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SURVEY AND EVALUATION OF SONIC FATIGUE TESTING FACILITIES

TECHNICAL REPORT No. ASD-TR-61-185

MARCH 1962

**FLIGHT DYNAMICS LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO**

Project No. 1370, Task No. 13963

APR 3 1962

(Prepared under Contract No. AF 33(616)-7000 by CONESCO
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FOREWORD

This report was prepared for the Flight Dynamics Laboratory, Directorate of Aeromechanics, Deputy for Technology, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio by CONESCO, Arlington, Massachusetts. The research work was accomplished under Air Force Contract No. AF33(616)-7003, Project No. 1370, "Dynamic Problems in Flight Vehicles", and Task No. 13963, "Sound and Vibration Simulation Devices and Procedures." The work was initially monitored under the direction of project engineers Mr. William Shilling and Mr. Davey L. Smith and later under the direction of Mr. Robert F. Cook, Dynamics Branch, Flight Dynamics Laboratory. The research covered by this report was initiated on 1 February 1960 and completed in January 1961.

We wish to acknowledge the cooperation of Messrs. W. Shilling, D. Smith and R. Cook, who provided valuable technical assistance through the course of this program. We also want to thank all the personnel at the various facilities considered, for without their kind cooperation and assistance this report could not have been written.

ABSTRACT

A survey and evaluation of the sonic fatigue testing facilities throughout the country has been made to establish present methods and techniques of testing and to determine the necessity of performing other environmental tests in combination with high intensity noise.

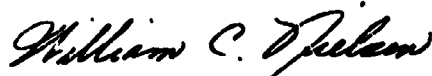
Fifteen facilities were visited and detailed descriptions of these facilities are presented. The facilities are considered in terms of their functions as design, proof testing, and research tools, and such things as sound sources, the theoretical background of sonic fatigue work, test methods and specimen arrangements, instrumentation and data acquisition, time and costs, and combined environments are discussed and evaluated. In addition, what are considered the most feasible design and proof testing procedures, within the framework of present theory and equipment, are presented. A few of the general conclusions are that:

1. The most economical procedure for developing sonic fatigue resistant structures consists of the general steps;
 - (a) Design panels with discrete frequency siren methods
 - (b) Perform semi-qualification tests with broad band sources such as broad band sirens or modulated air flow speakers (not jet engines).
 - (c) Perform a full scale proof test.
2. The effects of temperature and pressure (and perhaps corrosion) can only be assessed by combined tests.
3. Combined tests for nuclear radiation should not be considered in the foreseeable future.
4. In many instances the effects of correlation can be approximated in a discrete frequency siren test by orienting a specimen in a manner determined by consideration of the sound level contours existing on the aircraft.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER



WILLIAM C. NIELSEN
Colonel, USAF
Chief, Flight Dynamics Laboratory

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I PROBLEM OF SONIC FATIGUE

In recent years the problem of sonic fatigue has assumed great importance since, with the advent of high speed aircraft and rocket propelled missiles, many parts of a vehicle structure are subjected to a very intense sound field. Various facilities have been built to simulate this high intensity noise, and to evaluate the effect of such noise on structures. These facilities are necessary since the state of engineering knowledge does not permit a purely analytical design of structures to resist sonic fatigue.

The occurrence of acoustic fatigue in a structure is determined by the acoustic inputs, the dynamic response of the structure (i. e. modal geometry and amplitude), and the fatigue life of the material. The acoustic inputs are in the form of fluctuating pressures (usually random) on the exposed surface of the structure. They impose loads that vibrate the surface and, depending on such characteristics as geometry and method of construction, the structure will have certain modal shapes and amplitudes. These determine the stress patterns in the structure which, in turn, determine the fatigue life.

Measurements can be made of typical acoustic inputs and in some design cases (where the effects of space and time correlation of the acoustic field can be ignored) reasonable estimates of the sonic loads can be made.

The calculation of the stresses and the fatigue life is another matter, however. Because of such considerations as multi-mode and non-linear panel response and the uncertainty of panel edge fixity, a reasonably accurate calculation of the stresses is not possible, and even if it were possible, the fatigue life of the structure could be assessed only approximately since there is no precise theory for calculating cumulative fatigue damage.

This simplified picture of the sonic fatigue problem, which will be considerably enlarged on throughout this report, is sufficient to show the necessity of experimental facilities in the solution of such problems.

Most of the sonic fatigue facilities built by industry have been built under

the pressure of solving immediate problems. As a specific plane or missile was being developed or tested, sonic fatigue problems would appear and facilities would be required to solve them; thus, facilities vary in size, in types of test noise sources, in manner of testing, and in the manner of utilizing the test data. Where large and important programs have been involved and where sonic problems have been critical, the facilities tend to be large, several noise sources might be used, and involved methods of analysis might be employed.

While the above statements do not necessarily apply to government installations that have been built, it is true that their requirements are quite different from the private facilities since the government installations are usually oriented toward performing research. Thus they add to the multiplicity of facility types.

Test facilities are used for three main purposes, designing, proof testing, and research and development, and whether a facility is used for one or another of these tasks will greatly determine its layout and design. By a "facility used for design" we mean one in which detailed design configurations that can resist sonic fatigue are developed by means of analysis and testing or by means of comparisons of structures exposed to high intensity noise. By a "facility used for proof testing" we mean one in which a structural configuration is tested by exposing it to noise that simulates in some reasonable fashion the noise environment the structure will experience throughout its life. One distinction is that the design tool use implies fairly quick tests on a number of small specimens that will permit the general structure of the vehicle to be established while the proof testing use implies a rather lengthy test on sizeable segments of the vehicle or perhaps the entire vehicle. This distinction is not sharp but it is useful and will be amplified later in the report.

A. Objectives of the Facility Survey

Because of the numerous methods used in sonic fatigue testing and the various conclusions drawn from different types of tests it was felt by the Air Force that a study should be performed that would describe the test methods, point out the best type of information that was available from present tests, and show which approaches in sonic

fatigue testing would be most fruitful for further development. Also, since sonic fatigue can occur in combination with other service environments and since future flight vehicles may have to operate in unusually severe environments, the available facilities and possible methods for running combined environment tests should be known.

It was, of course, recognized that SF testing itself was a complex problem and that probably little had been done with combined environments but it was felt that, at least, the problems of combined testing could be defined and current practice outlined. Also of importance were the questions of whether combined tests were necessary or whether the effects of combined environments could be assessed by separate tests.

The program proceeded along the following general lines:

1. Questionnaires were sent, and visits were made to almost all of the facilities doing sonic fatigue work in the United States. Some contact was also made with foreign researchers.
2. Complete, detailed descriptions of the facilities were prepared. These included sound sources, instrumentation, methods of testing, methods of analysis, costs, and other environments available.
3. Evaluations were made that considered such factors as
 - (a) Comparison of test results with actual performance of the vehicle in service
 - (b) Complexity and cost of the test procedure
 - (c) Time required to carry the test to completion
 - (d) Suitability of tests for making design changes to rectify failures
 - (e) Reliability and applicability of methods of analysis
 - (f) Usefulness of the sound source for its given purpose
4. Based on all the information available to us, procedures (including comments on combined testing) were recommended that if followed in the various kinds of facilities, would give the most satisfactory results that could be expected, given the present state of the art.
5. The kinds of research and development work that should be carried out to most

quickly improve sonic fatigue prediction and also long range research programs were mentioned.

II BACKGROUND TO THE DESCRIPTIONS OF FACILITIES

Of central importance to the program was the gathering of accurate, up-to-date, and complete information regarding the facilities, and to insure that in our visits and discussions nothing was overlooked, a 15 page questionnaire was prepared. This questionnaire was sent to companies prior to our visit to give them some understanding of the kinds of information we were interested in, and then during the visit it was used as a guide to the discussions. In several instances the questionnaire was answered in some detail prior to the visit and this, of course, was very helpful. The questionnaire is summarized at the end of this chapter to illustrate the kinds of information requested. A comparison of the questionnaire with any one of the descriptions is interesting and shows what information is or is not available.

Descriptions are given only of installations performing structural sonic fatigue work. There are innumerable companies with small high intensity noise facilities that are used for testing electronic components. The noise sources in these units are of low output (compared with SF testing requirements), they are usually used in a reverberant chamber, and the tests are usually specification tests.

Because it was close by we visited one company that was concerned with such facilities, AVCO in Wilmington, Massachusetts. They sell a 220 cubic foot reverberant chamber for component testing that utilizes two large electro-dynamic speakers of their own design, two 18" cone speakers, and 20 to 40 high frequency speakers. The levels in the chamber ranged from 145 to 152 db. When the electro-dynamic speaker was attached to a 4" diameter plastic tube, noise levels of 170 db could be obtained in the tube at discrete frequencies and random broad band noise (20 to 5000 cps) could be produced at an overall level of 166 db.

In addition to not being adequate for SF testing, the component test facilities

are not concerned with the many problems associated with such testing so that they had little to contribute to this study.

There are several companies or agencies that were contacted or visited that are not included in the description, and we should like to list them here together with a few brief comments.

AVRO, Toronto, Canada

Although AVRO did some SF work in the past, the facility has not been active for some time.

HUGHES, Los Angeles, California

A small siren facility has recently been built at Hughes. It employs a 6" siren that puts out 2 kw of acoustic power over the frequency range 50 to 10,000 cps. A noise level of 168 db is obtainable in a duct 6" by 18" in cross section that leads to a 12 cubic foot chamber that can be either anechoic or reverberant. The facility is mostly useful for component testing.

REPUBLIC, Deerpark, Long Island, New York

Republic is planning a facility but nothing has been built. Mr. L. Gould (who worked on SF at AVRO) is concerned with this development.

BELL AIRCRAFT, Buffalo, New York

Bell has a reverberant chamber facility that uses electro-dynamic and electro-pneumatic transducers as noise sources. It is used mostly for the evaluation of electronic components, but it has also been used for evaluating the response of corrugated and honeycomb panels to acoustic excitation (Contract AF33(600)-37703).

SOUND DRIVE ENGINE COMPANY, Los Angeles, California

A high intensity siren facility was built for the Office of Naval Research in 1951 but not in connection with sonic fatigue work (see Report "High Amplitude Sound Abatement Research Program" by R. W. Lenard and O. B. Wilson, Jr., Contract ONR 70502, Project NR 014-907, October 1952). Some SF testing was done

for Douglas before 1956 but the facility has not been used in recent years.

GRUMMAN AIRCRAFT, Long Island, New York

A discrete frequency siren facility has been used to make designs on the A2F Navy Fighter plane. Sonic fatigue was not a severe problem so that only a small number of design tests (less than a dozen) were performed on 3 ft. by 3 ft. curved panels and no final proof tests were needed. The siren has a noise output of 160-162 db at the mouth of an exponential horn over the frequency range 100 to 1000 cps. Tests are run in a small semi-anechoic room. The design procedure is a variation of Miles analysis and Miner's cumulative damage rule is assumed. In a test the statistical properties of the panel response are determined by exposing the panel to jet noise for a few minutes. The life and the stress concentration factors in the panel are then determined by testing the panel at resonance with the discrete frequency siren at normal incidence and the life in a flight environment is determined by using the distribution measured in the jet field and Miner's rule. This information was gathered in a telephone conversation with Mr. Oliver McDaniel.

LEWIS FLIGHT PROPULSION LABORATORY, NASA, Cleveland, Ohio

A J-57 engine on a test stand has been used as a noise source in a program to make correlation measurements over a panel. Also pressure pick-ups have been mounted in one of the side panels of a B-47 jet bomber and correlation measurements made of the noise. Reports have not yet been released on these two programs.

PAM ASSOCIATES, INC., Baltimore, Maryland

PAM manufactures and sells a high intensity noise generator that has been developed from the broad band random siren designed at the Aero-Medical Laboratory, WADD (VonGierke, et al). They themselves are not concerned with sonic fatigue testing.

UNIVERSITY OF SOUTHAMPTON, England

These people are doing research on various aspects of sonic fatigue and their facilities are of modest levels and dimensions. They have 1 to 4 inch model air jets, a random siren that will produce levels of about 150 db, loudspeaker units, and a random fatigue testing rig. Some of their research work is discussed in Section IV.

It should be mentioned that a rough draft of each description was submitted to the respective facilities for their examination and comment and that the descriptions as given here differ from the rough drafts only (apart from organizational changes) in that many include suggested changes or new material supplied to us by the facility as a result of their examination of the rough draft. These descriptions, therefore, should be complete and accurate as of January 1961. In the case of Convair, San Diego, we were asked to submit the final draft to them for additional comments, but since time did not permit this, the description incorporates only their comments and additions to our rough draft.

SUMMARY OF SONIC FATIGUE QUESTIONNAIRE

1. Company name
2. Location of facility
3. Facility name or identifying number
4. Personnel interviewed
5. Date interviewed
6. General Description

There should be a brief but concise description of the salient features of the facility.

The following points should be brought out specifically:

- a) Power input
- b) Principal components

If possible, layout drawings and photographs of the installation should be included.

7. Kind of facility

This should be a more detailed description of the type of facility — identifying it as one of the following:

- a) Resonant enclosure
- b) Free field
- c) Direct coupling — mechanical linkage
 - acoustical
 - electro-magnetic
 - electro-static

If possible, detail drawings and/or photographs of the enclosure should be included.

8. Type of Sound source

Identify the sound source among the following and obtain the appropriate information. Give a detailed description of the sound generating device.

- a) Discrete frequency or line spectrum devices (e. g. single or multiple sirens)
 - Frequency or frequencies
 - Type of modulation or control
 - Intensity (or alternatively sound pressure level) at each frequency
 - Location at which intensity is measured
 - Spatial distribution at specimen location (with and without specimen)
- b) Modulated frequency devices
 - Number and basic frequencies of sirens
 - Range of modulation for each siren
 - Frequency of modulation for each siren
 - Are the modulations related? What is phase?
 - Intensity at each frequency
 - Location at which intensity is measured
 - Spatial distribution at specimen location (with and without specimen)
- c) Continuous spectrum devices (e. g. jet engine, air-modulated speaker, air jets, electromagnetic or electrostatic speaker)
 - Spectral density at specimen location
 - Is this measured at one point or at a number of points?
 - Is the spatial distribution (at the specimen) measured by octave bands?
 - If a proprietary device (such as a jet engine) is used, give manufacturer's specifications — e. g. type, thrust, etc.

- d) How does the sound source compare with the operating environment and what information do you have on the operating environment?

9. Specimens and test arrangement

How does the specimen represent the actual structure? (Is it the full sized object, a scale replica or a simplified structure?) Describe the various specimens used. If possible, obtain detail drawings. How are specimens selected (random choice or specially made)? Boundary or edge conditions - i. e. various ways of mounting. How do the conditions of mounting in the test correspond to those in the operating environment? Orientation of specimen with respect to sound source. Normal or grazing incidence. Are both sides of panel exposed to sound field?

10. Measurement System

a) Noise measurements

- 1) Describe the measuring system and the various instruments used (microphones, tape recorder, filter, level recorder, dynamic pressure gages, amplifier, correlation and analysis-state manufacturer and model number). Obtain a schematic diagram.
- 2) How detailed is the experimental determination of the sound field? What measurements are made? Is information available on the following:

Averaging techniques -	wide band noise
	octave band
	fractional octave band
	correlation in time and
	space
Wave form -	no. of zero crossings
	peak-to-peak amplitude
	R. M. S.
	Is oscillograph record
	available?

b) Specimen response measurements

- 1) Describe the detection system and the instruments used, manufacturer and model numbers (e.g. displacement measuring devices such as optical, capacitive, etc., stress measuring devices such as strain gages).
- 2) What is the rationale of locating strain (or stress) gages?
- 3) What measurements are made?

- 4) How is failure detected ?
- 5) How extensive does the fatigue crack have to be before the specimen is considered to have failed?
- 6) Is there a pre-test inspection for flaws or cracks?

11. Reduction and Interpretation of data

- a) What is the main purpose of the test program (fundamental research in metal fatigue, proof testing of new designs)?
- b) Are accelerated tests carried out - if so, describe the rationale behind these.
- c) How are data reduced - manually
automatic data processing
how long a test loop is used in
making the spectrum analysis
- d) How are test results summarized - i. e. what parameters are used to describe a test?
- e) What is used as the index of severity of a test - (maximum stress, equivalent stress, energy acceptance, sound power level)?
- f) What is used as the index of fatigue life (time to failure, number of cycles)?
- g) Have data been used to evaluate any cumulative fatigue theories (e. g. Miner's Linear Damage Law)? If so, what were the results?
- h) Get typical curves or other summary information for representative test runs.
- i) How do fatigue test results (prediction) compare with service life in actual environments?

12. Time and cost of tests

- a) Cost of specimens
- b) Approximate cost of complete facility and approximate operating cost per hour to run test.
- c) For a given panel configuration, how many specimens are prepared, how long does the program take, and what is its approximate cost?

13. Other test environments

- a) What environmental test facilities does the company have? (temperature, pressure,

radiation, other)

- b) Where are these located? Get drawings and description of facilities.
- c) Can these facilities be used in conjunction with the sonic testing? (Serial testing, simultaneous testing, steady-state or transient loading)
- d) What instrumentation is used to measure the characteristics of other environments? What measurements are made?
- e) How are tests related to sonic tests and what kind of combined tests have been run? Is active work being carried on to evaluate the necessity of combined testing – describe and get all available information. Discuss the problem of combined testing.

III DESCRIPTIONS OF SONIC FATIGUE TEST FACILITIES

The following is a list of the various people with whom the facilities were discussed and who supplied us with much of the information we needed:

BOEING, Seattle

Messrs. J. VanBronkhorst, D. Johnson, G. P. Wilson, F. M. Murray,
K. J. Young, L. Sullivan, and J. R. Fuller

BOEING, Wichita

Messrs. D. C. Crane, K. Walton, E. Cassidy, and D. L. Grande

BOLT BERANEK AND NEWMAN

Messrs. S. Labate, G. W. Kamperman, C. Allen and P. W. Smith, Jr.

CONVAIR, Fort Worth

Messrs. J. Robinson, G. Robinson, J. R. Ballentine, and H. Riepe

CONVAIR, San Diego

Messrs. G. Getline, B. J. Campbell, E. Kamps, and G. H. Boscoe

DOUGLAS, Santa Monica

Messrs. M. Miller, J. D. VanDyke, J. C. McClymonds, and T. Schultz

LOCKHEED, Burbank

Messrs. R. J. Cox, H. Thorpe, E. Landsberg, W. J. Krichlow, and J. Rebman

MARTIN, Baltimore

Messrs. R. H. Schwab and D. Thomas

MARTIN, Denver

Mr. G. S. Weller

McDONNELL, Saint Louis

Messrs. E. Pieper, J. Callahan, M. Hieken, and W. Mengel

NASA, Langley Field

Messrs. A. A. Regier, H. H. Hubbard, and P. Edge

NORTH AMERICAN, Columbus

Messrs. V. L. Beals, J. H. Hill, W. G. Dunn, B. Clymer, and J. Stocker

NORTH AMERICAN, Los Angeles

Messrs. W. B. Greenwood and P. M. Belcher

NORAIR DIVISION, Northrop Corp.

Messrs. D. C. Skilling, and W. W. McDowell

WRIGHT AIR DEVELOPMENT DIVISION

Messrs. A. Kolb, R. Shilling, L. Midolo, O. R. Rogers, and R. Cook

III-A. THE BOEING COMPANY
SEATTLE, WASHINGTON

1. GENERAL DESCRIPTION

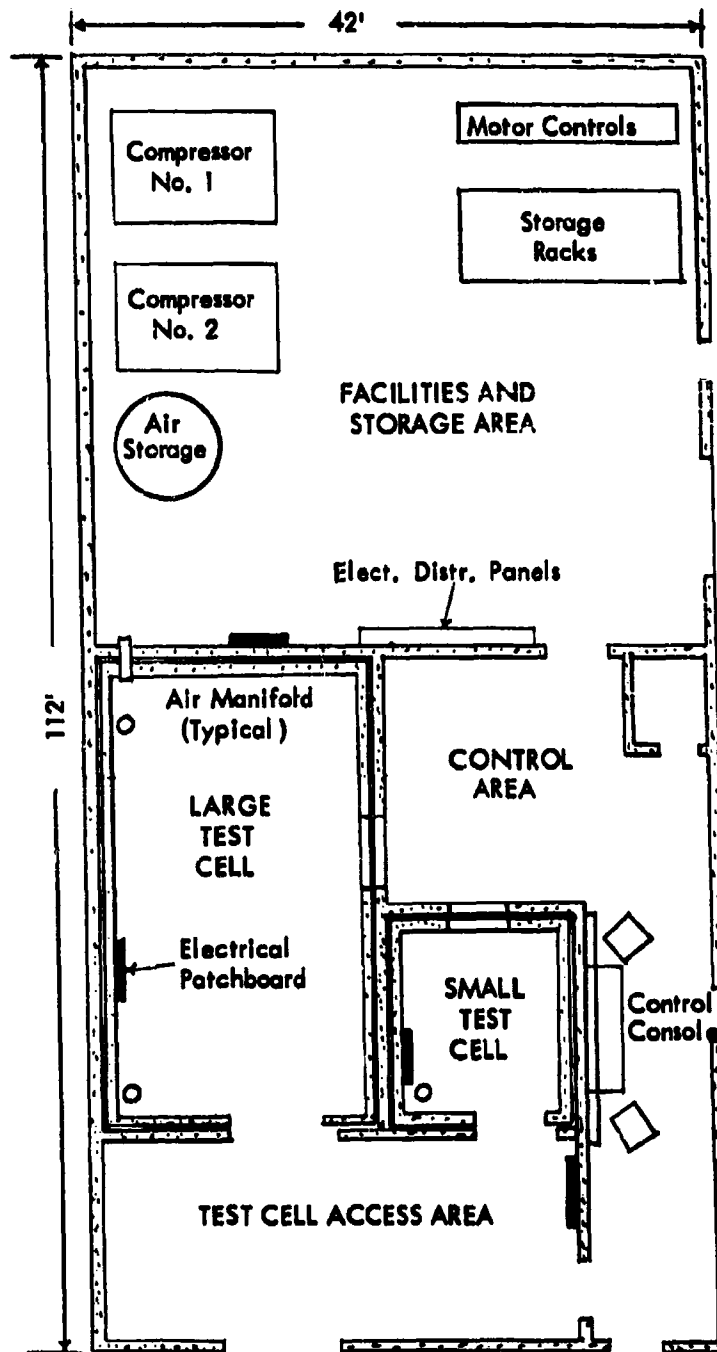
The Boeing Aero-Space Division is responsible for the Bomarc, Minute Man, and the Dyna Soar programs, and the Transport Division is responsible for the KC-135 Tanker, and the Boeing 707 and 720 Commercial Airliners. All of these project groups are concerned with sonic fatigue, and although they may use different testing methods and have different test requirements, the same facilities are used by each project group when performing tests.

Figure III A-1 is a floor plan of the building that contains the sonic fatigue facilities. The facility storage area contains two Joy Manufacturing Company WN-224 air compressors and associated air storage and control equipment (See Figure III A-2). These compressors rated at 350 HP each provide 4000 cfm of free air to manifolds located inside the test cells. This equipment is used to supply air to the sirens and air modulated speaker sound sources.

The small test cell is used with either a siren or air modulated speaker to provide reverberant chamber testing of specimens. The large test cell is a semi-anechoic enclosure and is used to test specimens where minimum reverberation is desired.

2. TYPES OF SOUND SOURCES

The sources used at Boeing, Seattle include discrete frequency sirens and air modulated speakers. Figure III A-3 is a schematic of the siren generators, table III A-1 tabulates the sirens and specifies the frequency range and sound level output of each, figure III A-4 is a photograph of a typical siren generator with a horn that is used



BOEING, SEATTLE

BOEING SONIC TEST FACILITY
FLOOR PLAN

FIGURE III A-1



AIR COMPRESSORS AND STORAGE

BOEING, SEATTLE

FIGURE III A-2

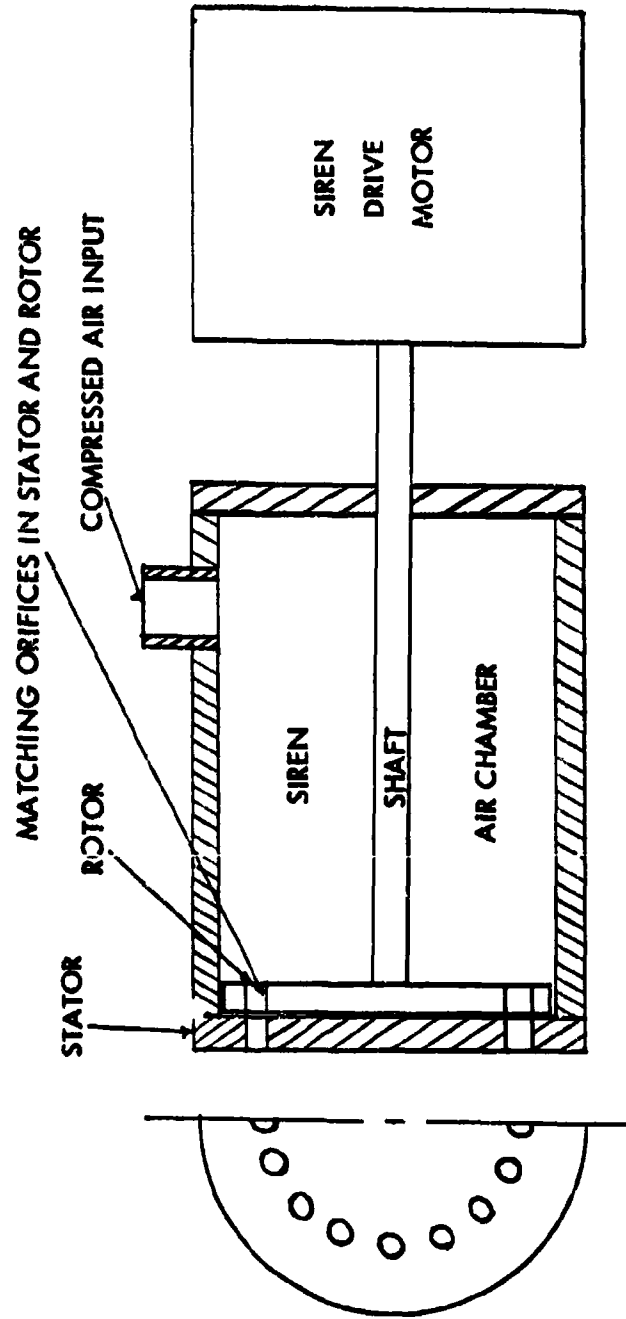
BOEING, SEATTLE

SONIC NOISE GEN.	COLOR CODE		MAXIMUM SOUND LEVEL RATING (db)	FREQ. RANGES (cps)
	HORN	CARRIAGE		
A	RED	BLUE	160	100 to 500 and 400 to 2000
B	YELLOW	YELLOW	170	100 to 600
C	YELLOW	RED	170	100 to 600

DISCRETE FREQUENCY SIREN OUTPUTS

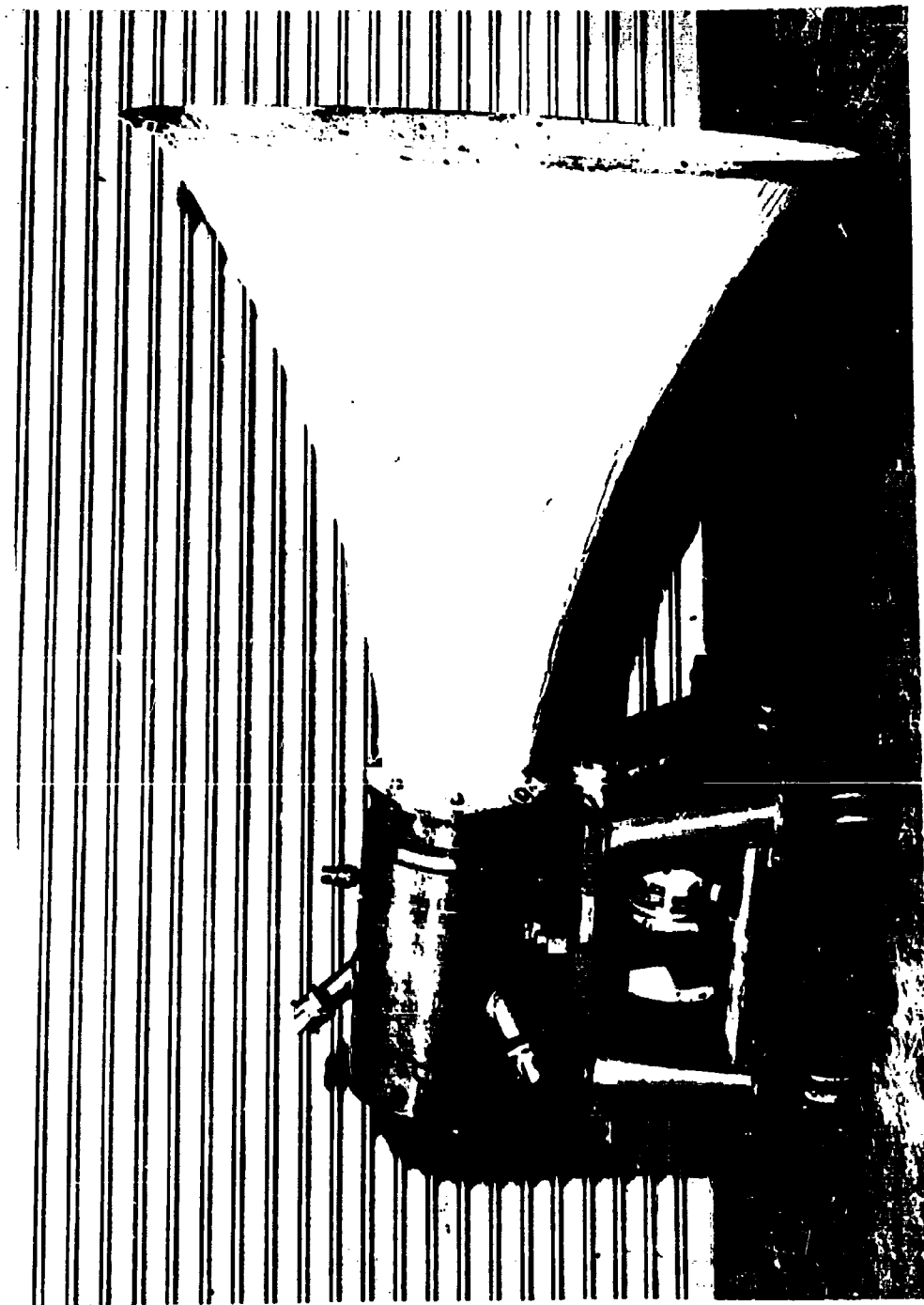
TABLE III A-1

BOEING, SEATTLE



BOEING SONIC NOISE GENERATOR

FIGURE III A-3



TYPICAL SIREN GENERATOR

BOEING, SEATTLE

FIGURE III A-4

for normal incidence testing, figure III A-5 shows a modulated air speaker system for normal incidence testing, and figure III A-6 shows a progressive wave test set-up. In Figure III A-6 two air modulated speakers are shown attached to the progressive wave chamber, but it may also be used with sirens as the sound sources.

The facilities break down into three general arrangements, a progressive wave chamber, a normal incidence test set-up, and a special set up used for the Minute Man Program.

(a) Progressive Wave Test Chamber

The progressive wave chamber can use either sirens or modulated air speakers as sound sources. The chamber consists of an exponential transition section, a test section, and an expansion horn. The exponential transition section consists of a laminated fiber glass outer shell and an internal cone that is installed inside the outer shell to provide a uniformly expanding cross-section between the sound source and the test section. The aft half of the test section is a continuation of the exponential transition section and it gradually expands to a 3" thick x 33" wide x 42" long test volume. Three removable wall pieces in the upper surface of the test section permit the mounting of flat test specimens 6" x 6", 12" x 12", and 24" x 24" respectively. The 42" long segment can be replaced by a longer assembly to test panels up to 24" x 48". The complete chamber set-up exhausts into an anechoic box to prevent sound reflections from re-entering the test section.

Figure III A-7 is an octave band plot of sound pressure level versus frequency for five microphone positions in a 24" x 24" test section when four modulated air speakers are used as the sound source.

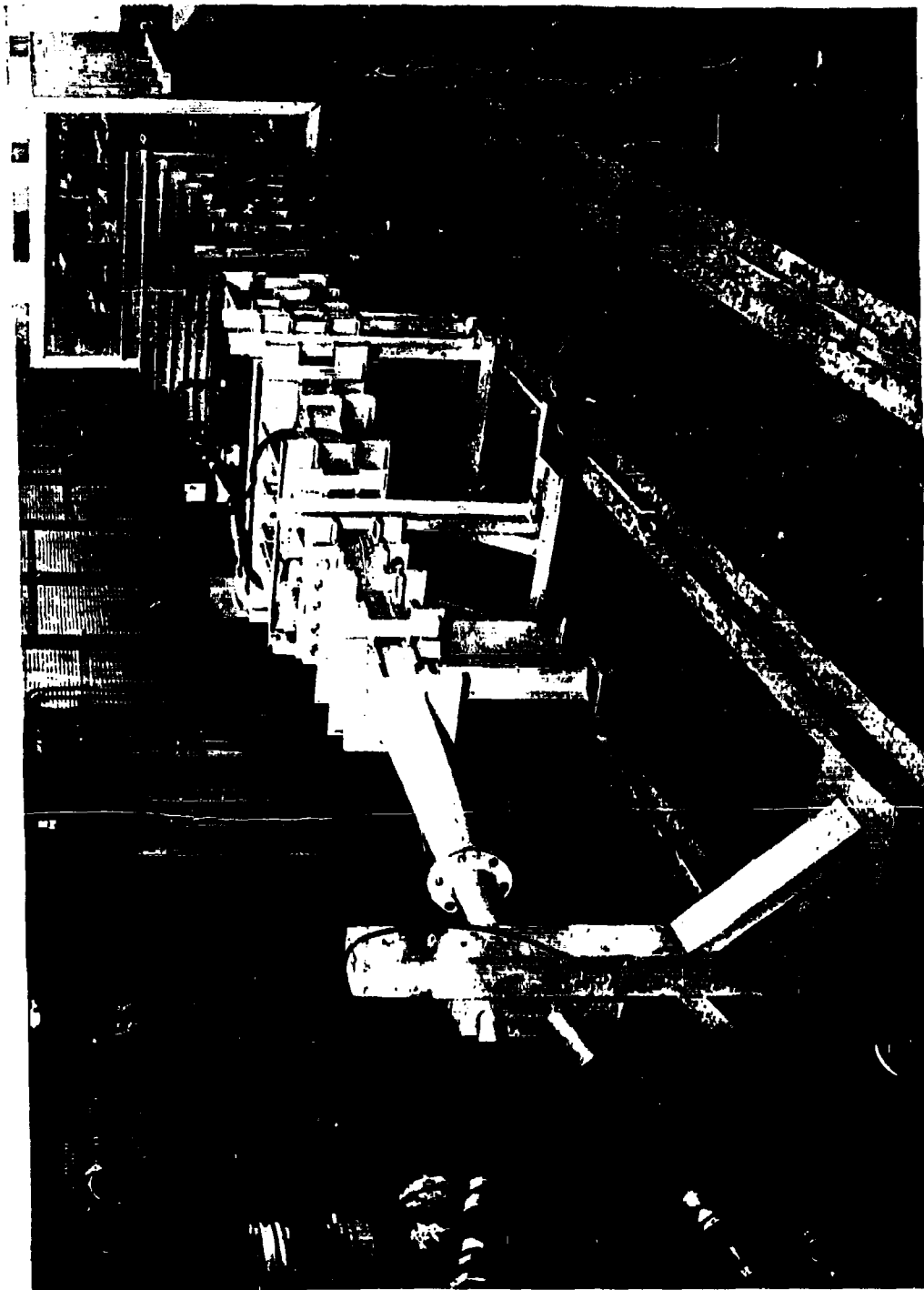
Figures III A-8, and III A-9 show the sound pressure level versus frequency plot for three microphone positions in the 24" x 24" test section when a siren is used as the sound source. Figure III A-10 is a combination of the three plots (smoothed data) to show the variation in sound pressure at the three microphone locations.



AIR MODULATED SPEAKER TEST SET-UP
(Normal Incidence)

BOEING, SEATTLE

FIGURE III A-5

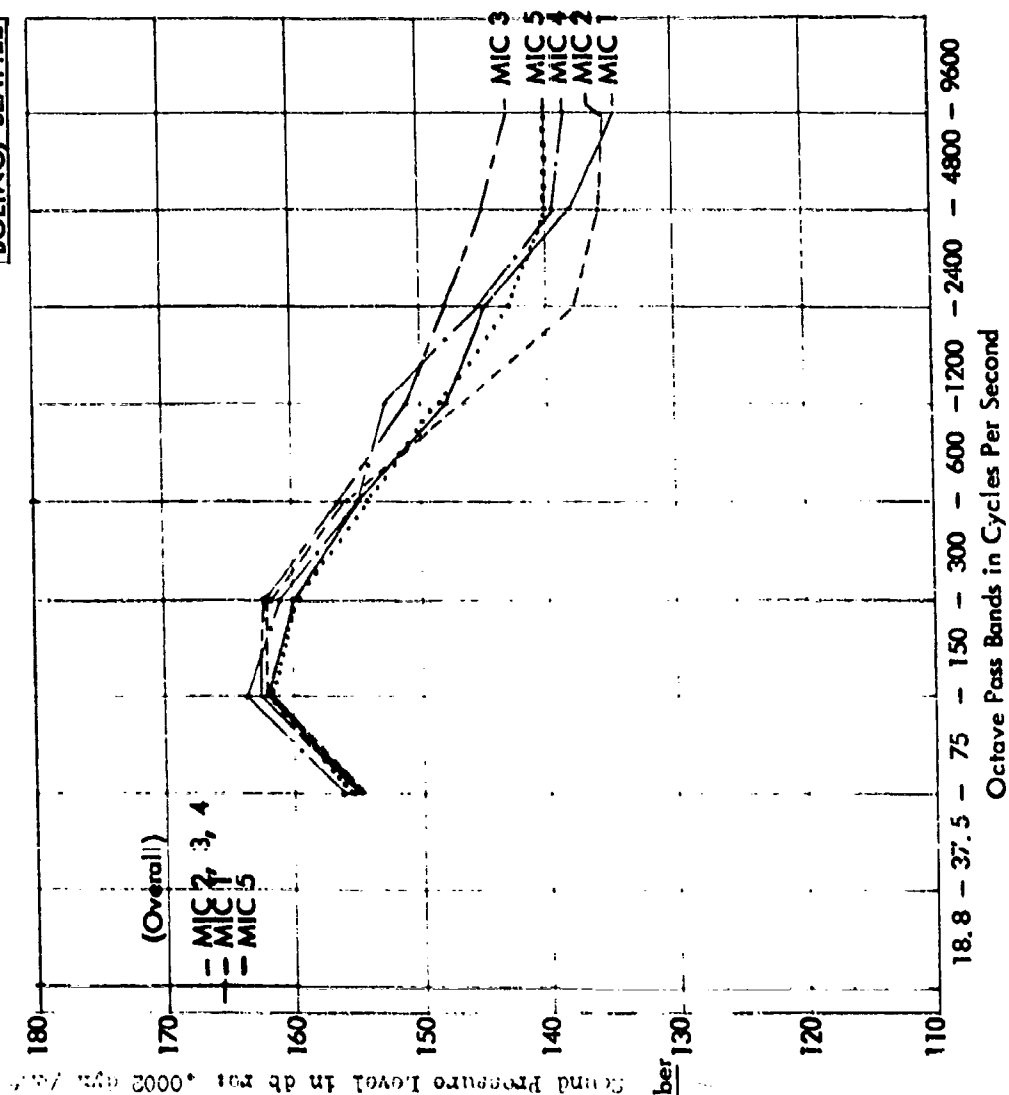


AIR MODULATED SPEAKER TEST SET-UP
(Progressive Wave)

BOEING, SEATTLE

FIGURE III A-6

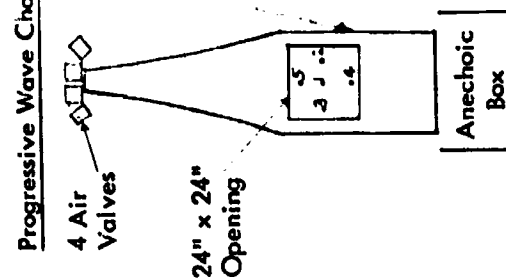
BOEING, SEATTLE



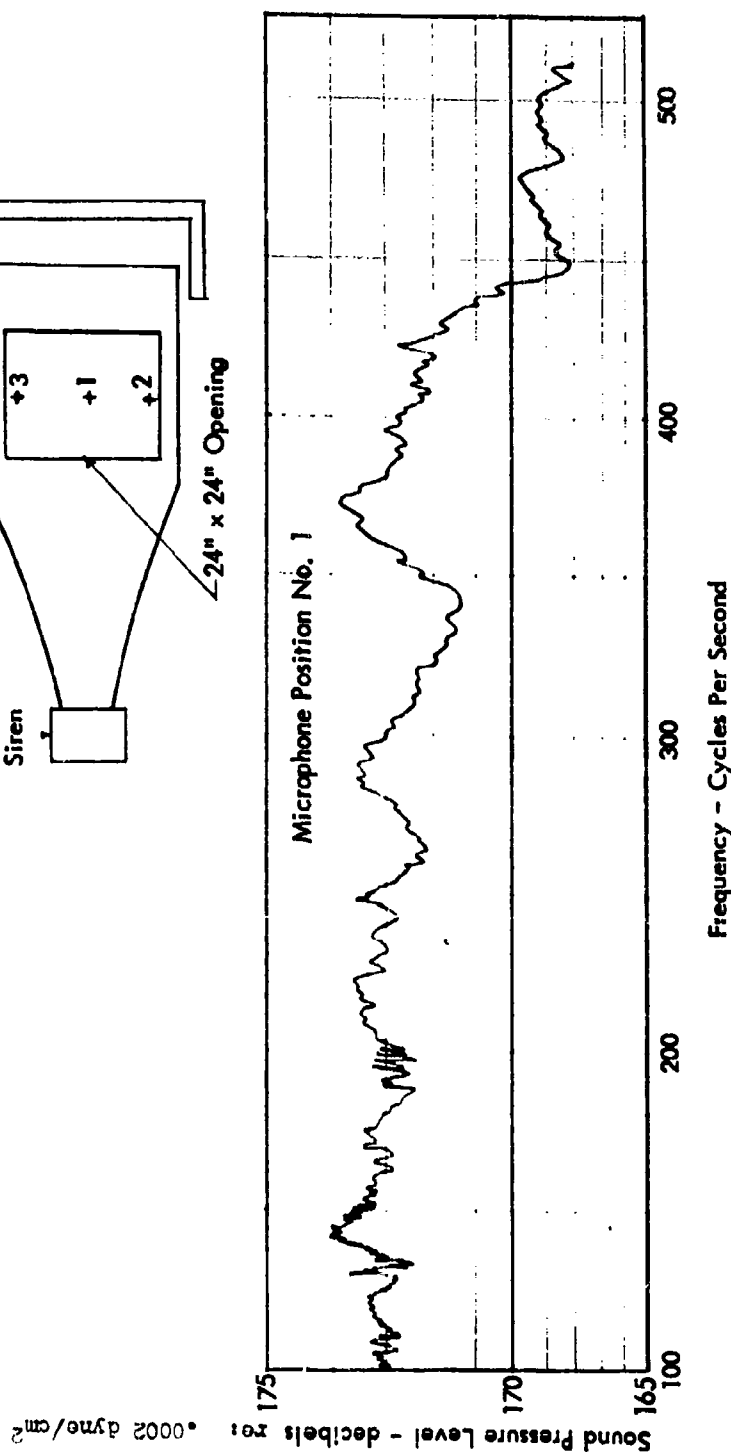
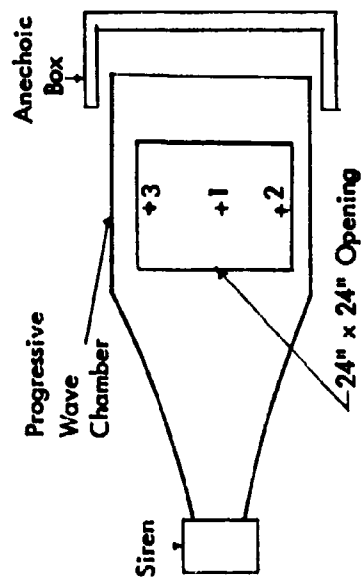
NOISE OUTPUT USING FOUR ALTEC-LANSING MODEL 6786
ELECTRO-PNEUMATIC TRANSDUCERS OPERATING AT MAX.
PRESSURE AND CURRENT

FIGURE III A-7

23



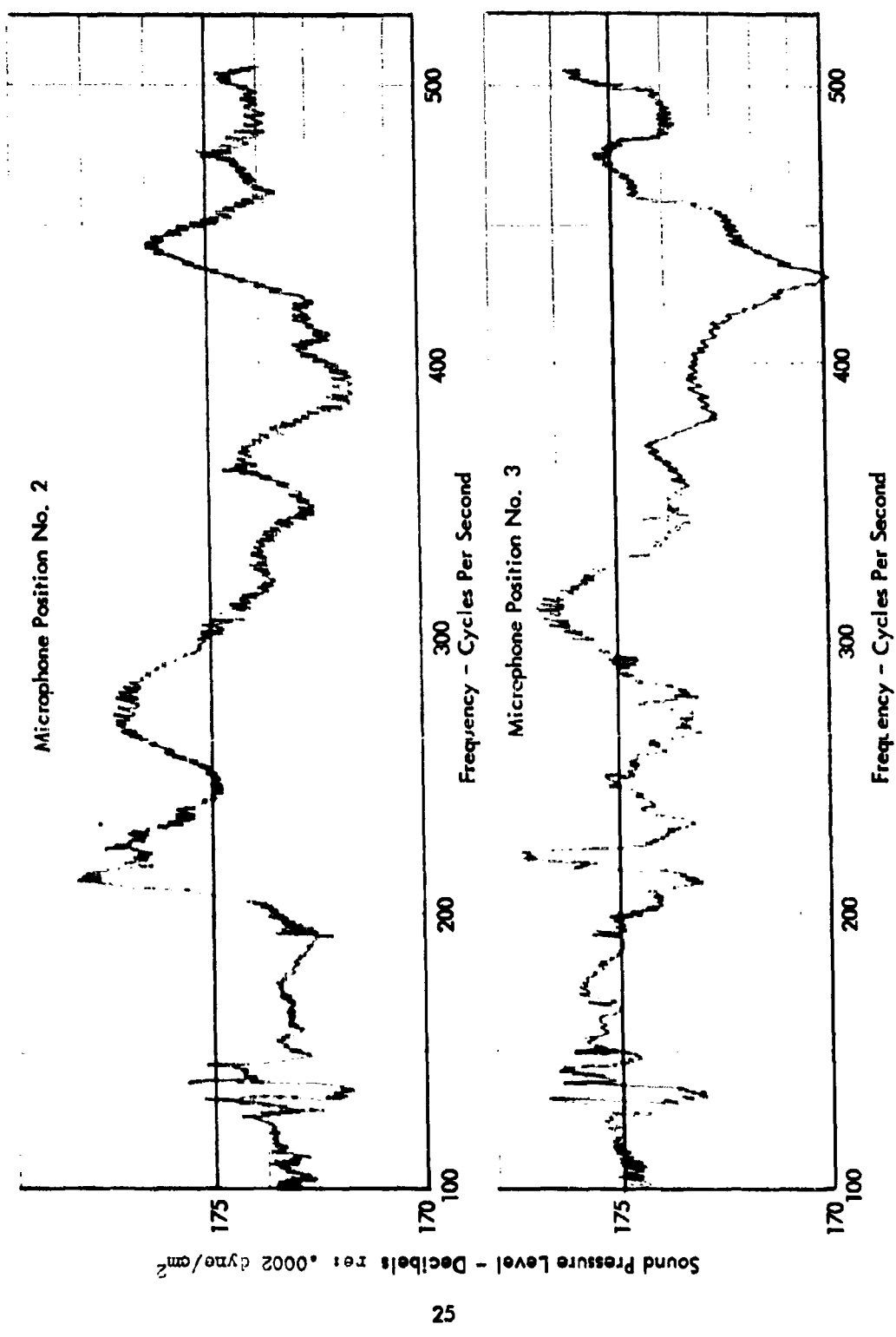
BOEING, SEATTLE



PROGRESSIVE WAVE CHAMBER MAXIMUM SOUND OUTPUT

FIGURE III A-8

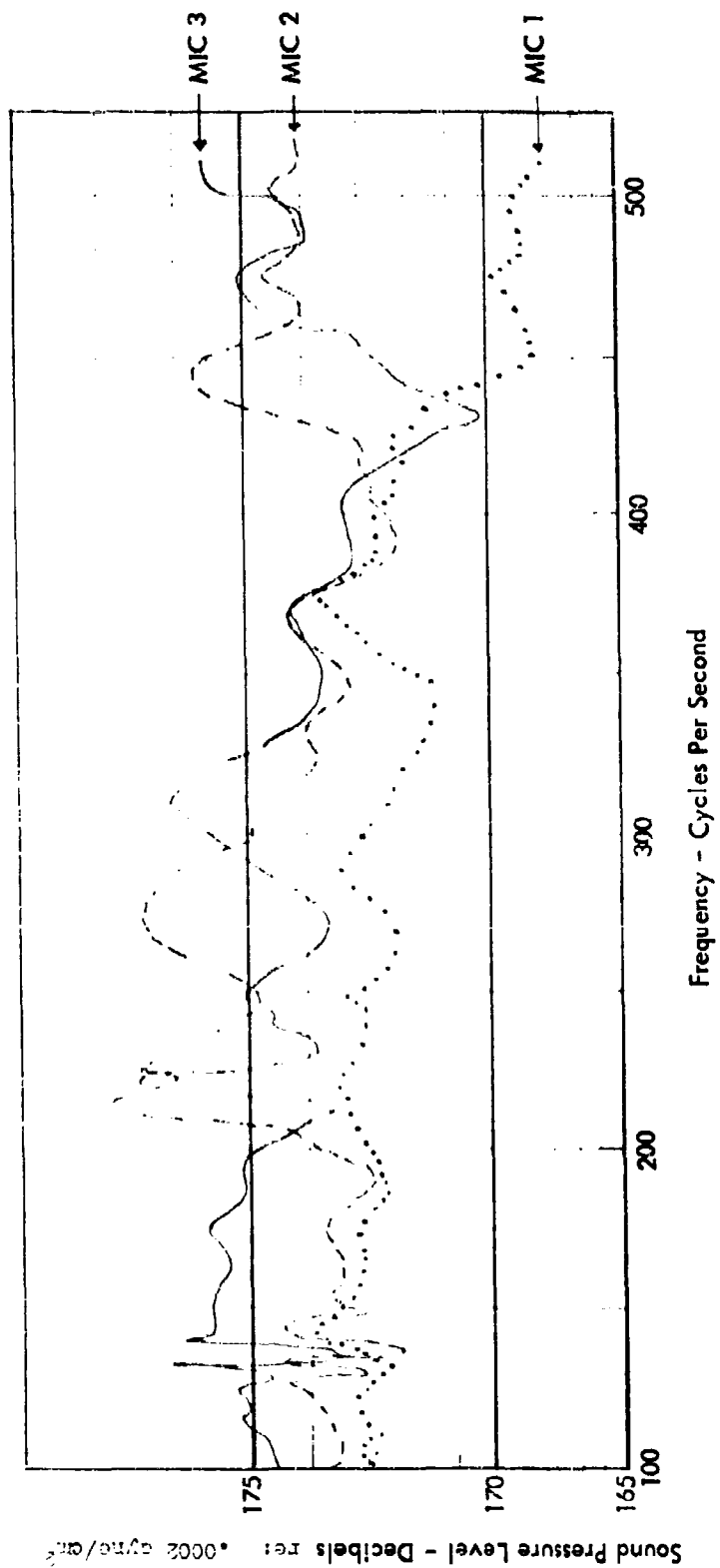
BOEING, SEATTLE



PROGRESSIVE WAVE CHAMBER MAXIMUM SOUND OUTPUT

FIGURE III A-9

BOEING, SEATTLE



SOUND PRESSURE LEVEL VARIATION AT THREE MICROPHONE POSITIONS

FIGURE III A-10

(b) Normal Incidence Test Set-up

For normal incidence testing, either the sirens or modulated air flow speakers are used as sources. Figure III A-4 shows the siren and Figure III A-5 shows the air modulated speaker set-up. The specimen to be tested is simply placed a few inches away from the horn mouth and excited. The modulated air speaker system for normal incidence testing is quite new and information on its characteristics is not available at the present time.

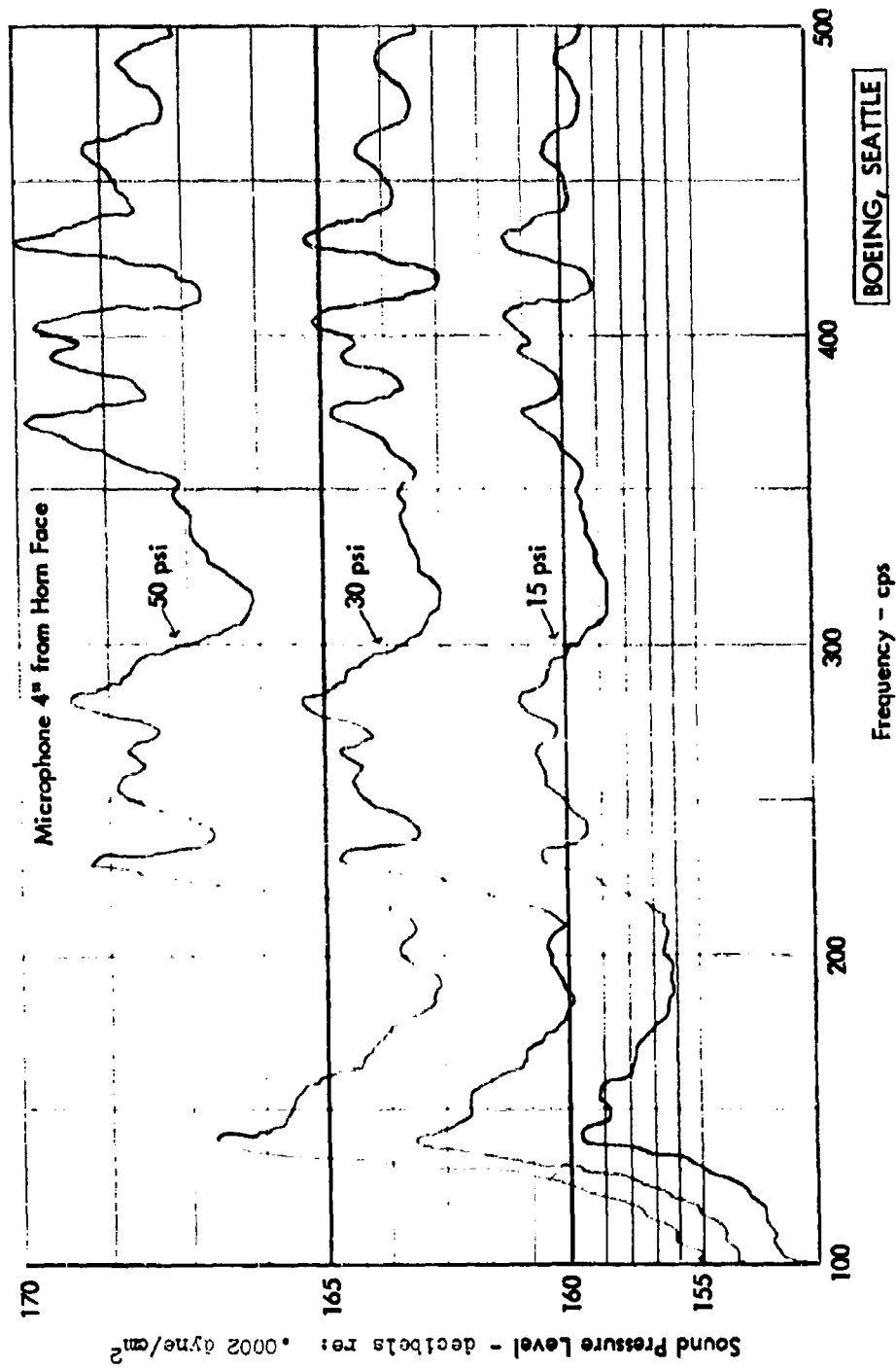
Figure III A-11 shows the sound pressure level versus frequency plot for the siren (at three siren chamber pressures) with a conventional horn

(c) Special Minuteman Test Setup

Three special test jigs were built under the Minuteman Missile Program for Flight Proof Testing of the Minuteman Instrumentation Section and two interstage configurations. All test specimens were structurally complete sections with electrical components, antennas and wiring installed. These tests were conducted to determine response of structure and attached components to vibration resulting from random noise fields duplicating the predicted silo launch environment for each of the test sections.

Each test jig consisted of a large cylindrical casing coupled to Altec Lansing Model 6786 Electro-Pneumatic transducers (four or eight, depending on the section tested) through semi-exponential horns having 40 cps flare rates on two sides.

The test section was placed concentrically within the casing (approximately 1.5" clearance) and the horns (with transducers) were attached to the end of the casing and equally spaced around the circumference. The horns were designed to have their axes parallel to the axis of the missile and to radiate sound into the annulus (formed by the missile and the casing) as progressive waves that travel along the length of the specimen. The desired test spectrum of the noise field was shaped using an octave band equalizer and analyzer system with one microphone near the specimen for control. The sound pressure level at each microphone used on the test was tape recorded and a narrow band (usually 4 cps bandwidth) analysis was made on a Davies analyzer.



SOUND PRESSURE LEVEL VS FREQUENCY FOR NORMAL INCIDENCE SIREN

FIGURE III A-11

The phase of the Minute Man program noted above was primarily one of testing instruments and components within the housing for malfunction rather than one of testing the structure for sonic fatigue, and most of the tests were of short duration (up to one minute) at overall levels in the 160 - 165 db range.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

The noise sources that are presently available for sonic fatigue testing are used in both normal and grazing incidence tests. The actual testing method, duration of test, and the specific noise level of the test are determined by project requirement. For panel testing in general, panels are tested at resonance which is determined by scanning the frequency range. On small specimens, usually one microphone near the center of the specimen is used, while on larger specimens, up to 4 microphones may be used. A plot of sound pressure level versus frequency is made for each individual siren test level, and a specimen amplitude versus frequency plot is often made at the same time. On random noise tests, microphone sound pressure levels are recorded and analyzed to determine the sound field around the specimen. Narrow and/or octave band analyses are made, and sometimes a count of the number of peaks exceeding a given level is made to determine the ratio of peak to rms level which is then compared with a Rayleigh distribution curve. Strain gages are placed at points of high average stress or at locations for which stress calculations have been made for comparison with the test results. The measurements made during discrete frequency testing include peak-to-peak specimen amplitude, stress at a given frequency, and sound pressure level. The measurements made for random noise tests include rms specimen amplitude, peak amplitude distribution, rms stress, and peak stress distribution. Fatigue failure is detected by observing changes in the resonant frequency or specimen amplitude of vibration, by making periodic visual inspections, or by periodic dye checking of the specimens. The specimen is usually considered to have failed when a fatigue crack is visible to the eye.

Most specimens undergo a Boeing Company inspection before they are released from the fabrication area, and in addition, a general visual inspection is made in the sonic

laboratory prior to testing.

Specimens may be especially made to fit an existing sonic test jig (such as the progressive wave chamber) or an entire set of complicated jigs may be fabricated. On structural specimens, boundary conditions vary from close-tolerance-bolts clamping all four edges of a flat panel, to rubber-mounted shock absorbers used to suspend the specimen inside a progressive wave chamber. In some cases, an attempt is made to duplicate boundary conditions on a panel by preparing specimens composed of several panels and in which the center panel of the specimen may be considered as having the same boundary conditions as it has on the plane.

In general, grazing incidence testing is preferred because considerably fewer problems with standing waves are encountered.

4. INSTRUMENTATION AND DATA ACQUISITION

(a) Noise Measurements

The sound pressure level at the specimen is measured with Altec Lansing condenser type microphones (model 21BR-200). The overall sound pressure level is read either on a Hewlett-Packard or a Ballantine VTVM. On discrete frequency siren tests, the sound pressure level is plotted against frequency on a Mosely autograph X-Y plotter or a El X-Y plotter.

On random noise tests the microphone output is sent through a line amplifier to the tape room for tape recording and later a Davies narrow band analysis or an octave band analysis on a General Radio analyzer is made. A design spectrum is usually given to the facility by a project group, and a comparison of the actual spectrum produced and the one specified is made.

As has been noted, up to four microphones are used for noise measurements in a test.

(b) Response Measurements

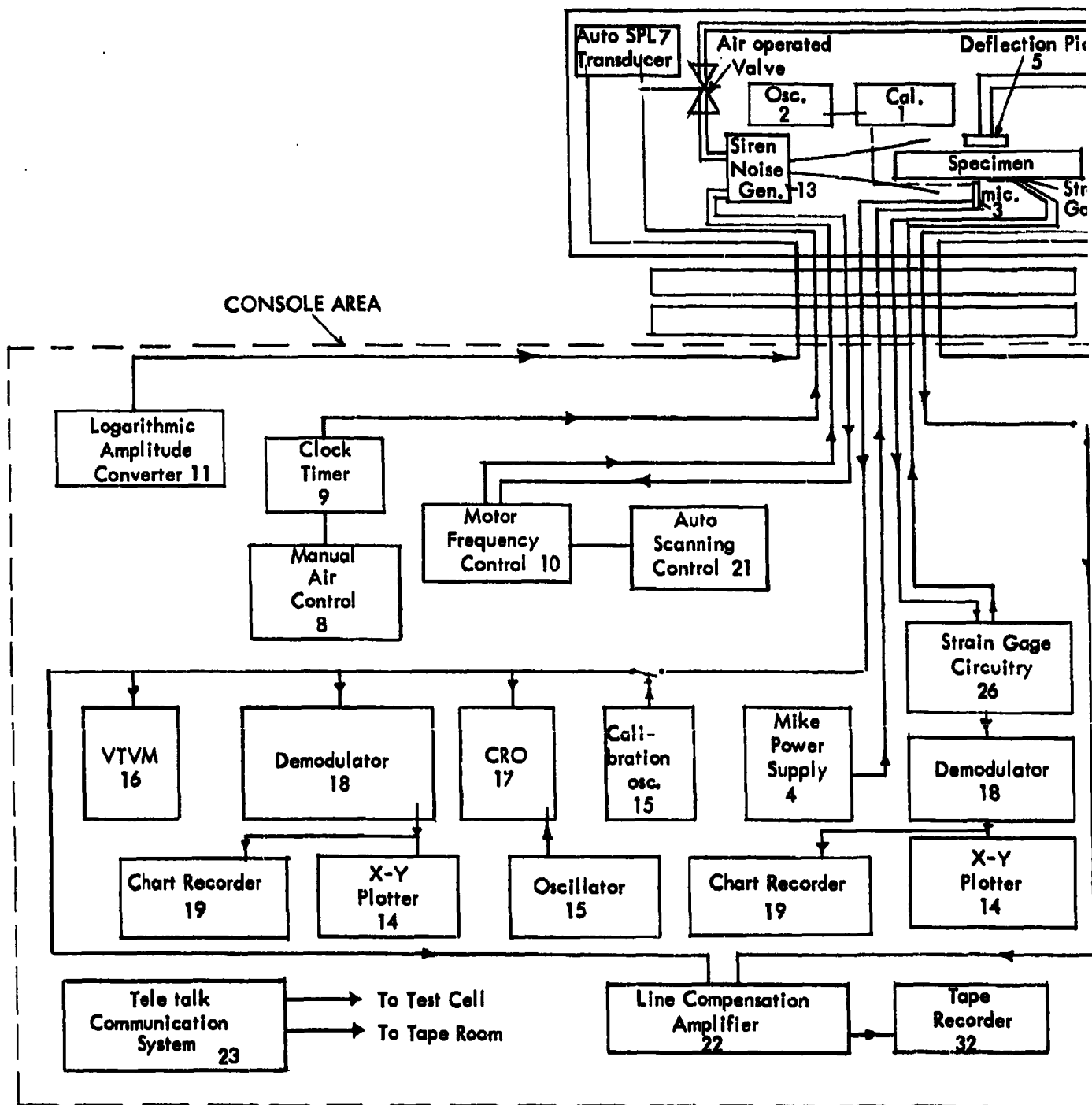
Specimen response is measured with non-contact amplitude pick-ups and/or strain gages. Commercially available strain gages are calibrated in the laboratory and used to indicate stress levels. The output of a given strain gage is automatically plotted on a Mosely

X-Y recorder as stress versus frequency (discrete frequency tests).

(c) Instrumentation

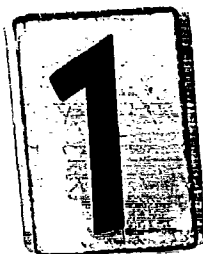
The following is a list of the equipment and instrumentation used in discrete frequency and random noise testing. Figures III A-12 and III A-13 are block diagrams that show the relationship of the various instruments and the equipment. The block diagram numbers correspond to the numbers on the list.

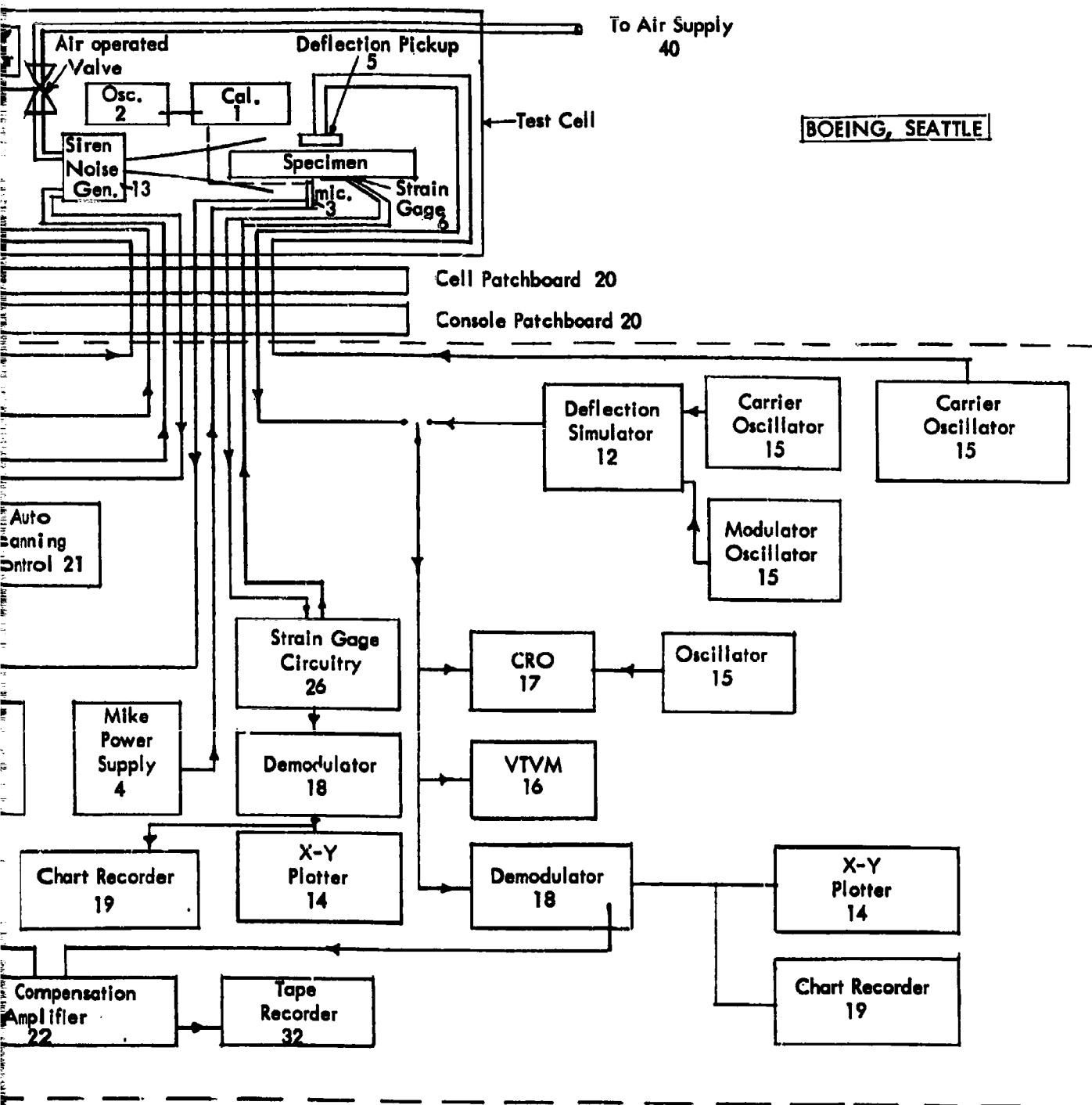
1. Two General Radio sound level calibrators, type No. 1552-B - used to calibrate sound level microphones.
2. One General Radio transistor oscillator, type No. 1307A - used to produce signal for G. R. sound level calibrator.
3. Ten Altec-Lansing microphones, type No. 21-BR-200-1 - used to measure sound pressure level.
4. One Boeing 4 channel microphone power supply used to supply voltage for cathode follower in microphone and adjust output to a suitable base.
5. Twelve one-inch, twelve two-inch Electronic Development laboratories non-contact deflection pickups - used to measure peak to peak amplitude of specimen deflection.
6. Strain gages - any commercial gage specified by test initiators.
7. One Minneapolis-Honeywell pneumatic control system; M. H. tel-o-set controller, model 822A1, M. H. 1/p transducer, model FC 301-3 - used to maintain constant sound pressure level versus frequency scan.
8. Pneumatic Control System - used to set the air pressures in the sonic generators and allow visual observation of air flow conditions in the Sonic Test Facility at all times.
9. Two Gra-Lab electric timers - used to set the correct time interval for a test.
10. Two Boeing fabricated motor control units - used to set and automatically maintain the output frequency of the siren motors.



INSTRUMENTATION BLOCK DIAGRAM DISCRETE FREQUENCY

FIGURE III A-12



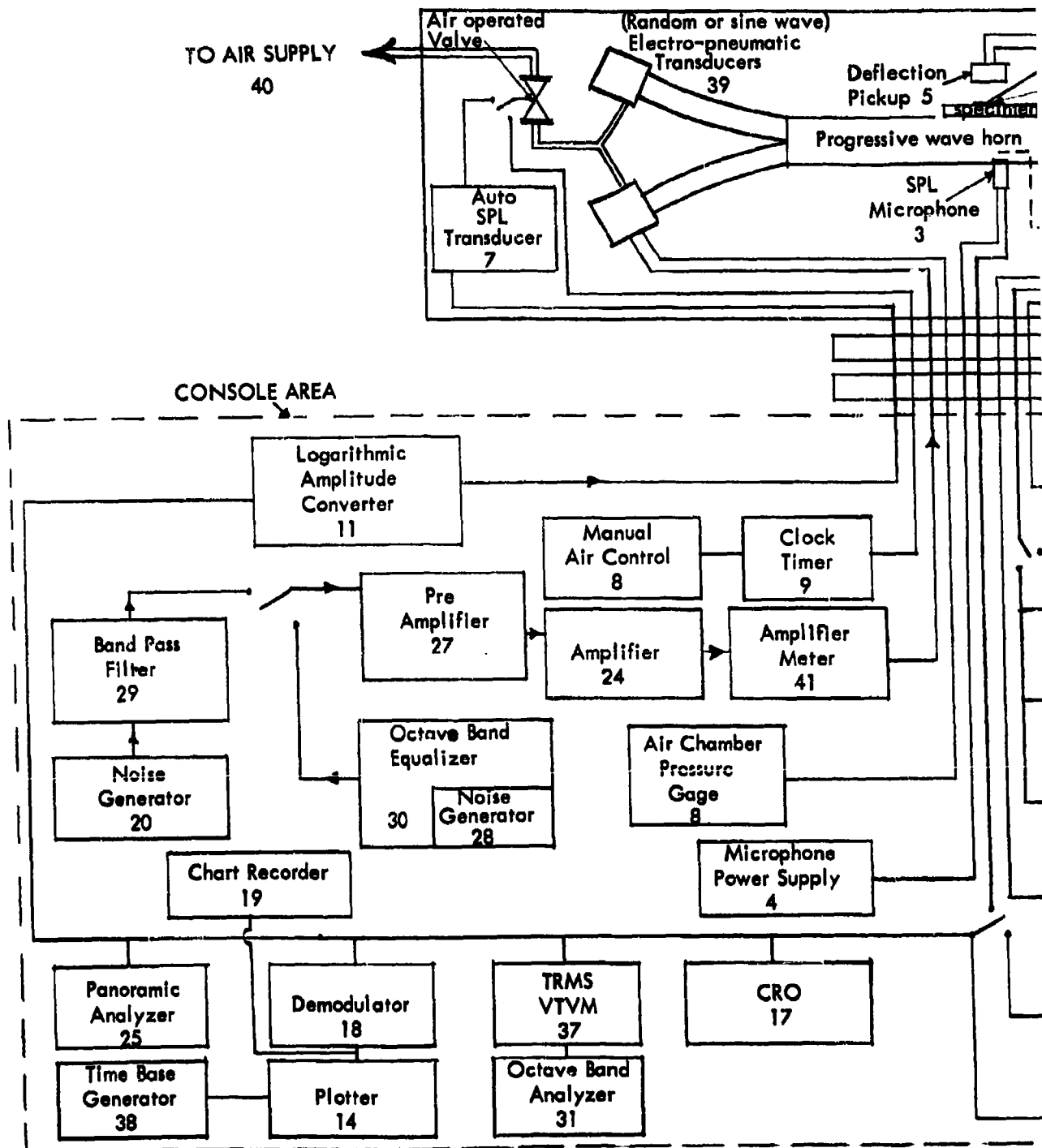


BOEING, SEATTLE

BLOCK DIAGRAM DISCRETE FREQUENCY SONIC TESTING

FIGURE III A-12

NOTE: Numbers in blocks refer to instrumentation list starting on page 31.



1

INSTRUMENTATION BLOCK DIAGRAM RANDOM N

FIGURE III A-13

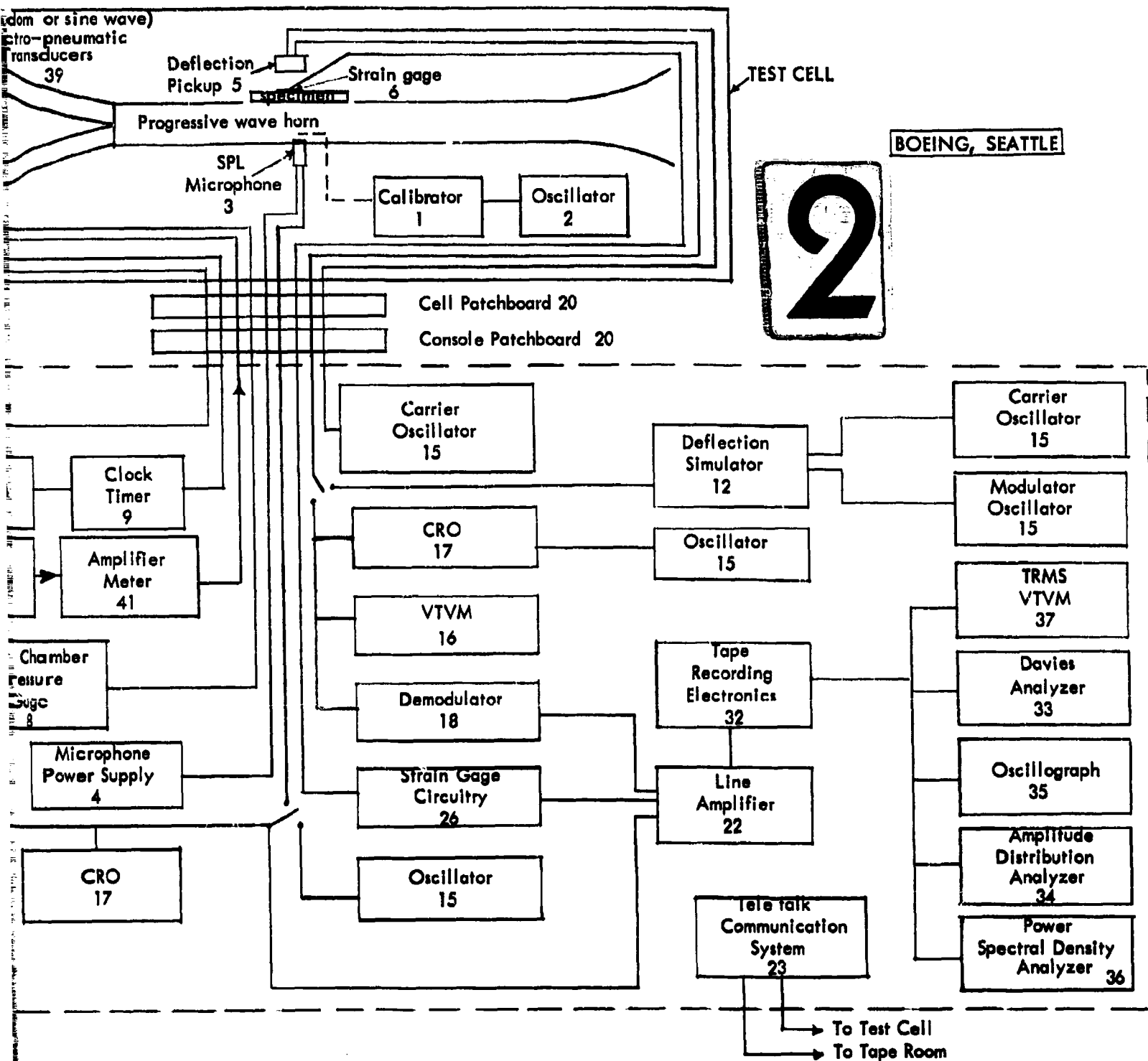


FIGURE III A-13

NOTE: Numbers in blocks refer to instrumentation list starting on page 31.

11. One Boeing fabricated logarithmic amplitude converter - used to compress the microphone signal to proper limits prior to transmission to the Automatic Sound Level Control System.
12. One Boeing fabricated deflection simulator - used to simulate deflection for instrument calibration.
13. Four Boeing fabricated sirens - used to produce sinusoidal wave sound, 30-3000 cps.
14. Four Mosely Autograf X-Y plotters - used to record sound level, specimen amplitude, and strain gage response as a function of frequency.
15. Four Hewlett-Packard Model 200AB audio oscillators - used to provide a reference and carrier frequency during calibration and testing.
16. Four Hewlett-Packard vacuum tube voltmeters (2 Model 400 AB, 1 Model 400H, 1 Model 410B) - used to measure voltages and microphone sound level output during calibration and testing.
17. Four Hewlett-Packard oscilloscopes (Model 130A and Model 130BR) - used to observe wave forms of microphone output and specimen response.
18. Four Boeing fabricated demodulator units - used to convert the carrier output of an amplitude pickup to operate a deflection meter, strip chart recorder or X-Y plotter.
19. Four Esterline-Angus strip chart recorders - used to record a variable such as sound level, amplitude, strain gage response, etc. as a function of time.
20. Two Boeing fabricated electrical patchboards - one from each cell to transmit data from the test setup to the controlling and recording instruments.
21. Two Boeing fabricated automatic scanning control units - used to set the frequency scan time of a siren to a desired rate.
22. One Boeing fabricated 14-channel amplifier - used to amplify instrumentation signals for transmission to the recording and analyzing equipment in the Structures Laboratory Tape Room.
23. Two Teletalk communication systems - used for voice communication to the test cell area and the Tape Room Facility.

24. **Four McIntosh 200 watt amplifiers - used to drive the voice coils of the Altec-Lansing air valves.**
25. **One Panoramic Sonic Analyzer Model LP-1 - used to observe the random noise spectrum of the Altec-Lansing air valves.**
26. **Strain gage potentiometer circuits - used to measure and record dynamic strain in spectrum.**
27. **One General Radio unit amplifier, type 1206B - used as preamplifier for noise generator output.**
28. **One Boeing fabricated white noise generator - used as noise source for Krohn-Hite band pass filter.**
29. **One Krohn-Hite Instrument Co. variable band pass filter - used to control frequency range of electro-pneumatic transducer output.**
30. **One Allison multiple octave band equalizer - used as source and to shape random noise sound spectrum.**
31. **One General Radio octave band noise analyzer, type No. 1550A - used to measure sound level in octave bands.**
32. **Three sets of Ampex tape recording electronics: types FL-107-7 channel, FR-107-7 channel, TB 14 channel - used to record sound level and deflection data for analysis.**
33. **One Davies automatic wave analyzer system, model 901D - used to analyze sound spectrum and random deflection data.**
34. **One Boeing fabricated amplitude distribution analyzer - used to analyze random sound level spectrums and specimen amplitude deflection data.**
35. **One Consolidated Electronics Corp. recording oscillograph, 32 channel - used to record sound, deflection, and electro-pneumatic transducer input wave forms.**
36. **One Technical Products Corp. power spectral density analyzer, model TP-625- used for sound pressure level spectrums and amplitude deflection spectrums.**

37. Two Ballantine laboratories true-root-mean-square voltmeters, model 320 - used for measuring random type voltages.
38. One Boeing fabricated time base generator - used to provide time axis on X-Y plotters.
39. Eight Altec-Lansing electro-pneumatic transducers - used to produce random and sinusoidal noise.
40. Two Joy air compressors, model E, class WN 224, 400 horsepower - used to supply air to sirens and electro-pneumatic transducers.
41. Two Weston AC ammeters - used to measure current to transducers

5. INTERPRETATION OF DATA

Hitherto, it has been usual to base the interpretation of data and the prediction of fatigue life on Miner's linear accumulation hypothesis, but recently, an alternative method of estimating damage accumulation and predicting fatigue life has been proposed by J. R. Fuller. Both of these methods are discussed below.

As an example of the prediction of a service failure based on Miner's hypothesis, we will consider the case of the sonic fatigue of fuselage skin panels in the KC-135 aircraft.

There were indications that this aircraft suffered some fatigue cracking in the aft body after approximately 3 hours of maximum wet power during ground sonic testing. To counteract this, circumferential straps were added, and the predicted effect on fatigue life was determined in the following way:

The rms stress and the statistical distribution of the peak stresses were found from strain gage recordings obtained for the critical location on the 'basic' or 'unstrapped' aircraft when the engines were being run at maximum wet power. The stress range obtained from the strain records was then divided into 20 intervals, and the number of stress peaks occurring in each interval during a 1-hour period was found from the distribution and the average number of peaks on a 4-second record. Since the critical rms stress (at the point where failure eventually occurred) was unknown

because the strains were measured adjacent to a row of skin-stringer spotwelds, the next step was to assume some ratio between the actual rms stress at the edge of a spot-weld and the measured rms stress. This ratio was used to 'adjust' the previous stress intervals, thereby obtaining a tentative distribution of stresses at the location of eventual failure. Using the number of stress peaks in an adjusted interval and the corresponding cycles to failure from an appropriate S-N curve (sinusoidal), the incremental damage associated with each stress interval (for a 1-hour period) was found from Miner's cycle ratio $\frac{n_i}{N_i}$. By summing this over all the stress intervals, the hourly accumulation of damage was found and the reciprocal of this gave the life in hours.

Repeating this for a number of assumed ratios of critical stress to measured stress allowed the correct 'adjusted' rms stress (one that would give the 3-hour measured life) to be found.

This procedure was repeated using the same strain gages after the circumferential straps were applied to the airplane and the same ratio was used to adjust the measured rms stress thereby yielding a prediction of the improved life resulting from the strapping.

A technique for estimating service life of an aircraft was developed in a study of structural fatigue of the B-52 series of aircraft (B-52B through B-52G). It is based on an approach which is fundamentally the same as that used in the study of the KC-135 but assumes a Rayleigh distribution of peak stresses rather than an experimentally determined distribution. The technique uses a mission profile covering a typical year of operation of the aircraft. This mission profile takes the average annual flight time and breaks this down into periods at different engine powers; each period is then associated with a different sound pressure and hence an rms stress level. The connection between engine power, sound pressure, and stress is established experimentally. Assuming a Rayleigh distribution of stress peaks and referring to an orthodox S-N curve, the cumulative damage (as defined by Miner's summation of cycle ratios) for each period is found. From this the annual damage rate is found and thence the estimated service life of the

aircraft.

Recently, J. R. Fuller devised a method for estimating fatigue life under variable-amplitude cyclic loading which does not use Miner's linear accumulation hypothesis. The method is based on the premise that if a specimen is cycled under some variable load pattern between two limiting over stresses, the greater of which is S_A and the smaller S_a , then failure may be expected to occur at some number of cycles greater than that which would cause failure by cycling at S_A alone and less than that which would cause failure by cycling only at S_a . The interpolation of the actual variable-amplitude life between these two limiting lives is carried out by means of the formula

$$N_v = N_a \left(\frac{N_A}{N_a} \right)^\beta$$

where N_A and N_a are the fatigue lives at the upper and lower stress levels respectively and the exponent β reflects the distribution of stress levels between the upper and lower limits. The value of β is found by plotting the distribution of stresses in 1000 cycles on a semi-log grid and taking the ratio of the area under the curve to the area of the grid

The method is empirical and proceeds from consideration of the differing geometries of the fatigue-life curve under constant-amplitude loading and variable-cycle loading.

When applied to an extensive series of variable-cycle tests reported by Freudenthal the method predicted fatigue lives that agreed well with measured values. Acceptable agreement was also obtained when the method was used with random-amplitude data reported by Trotter. It has not yet, however, been used for the prediction of service failure on an actual aircraft structure.

6. TIME AND COSTS

The costs of specimens vary from a few dollars to many thousands.

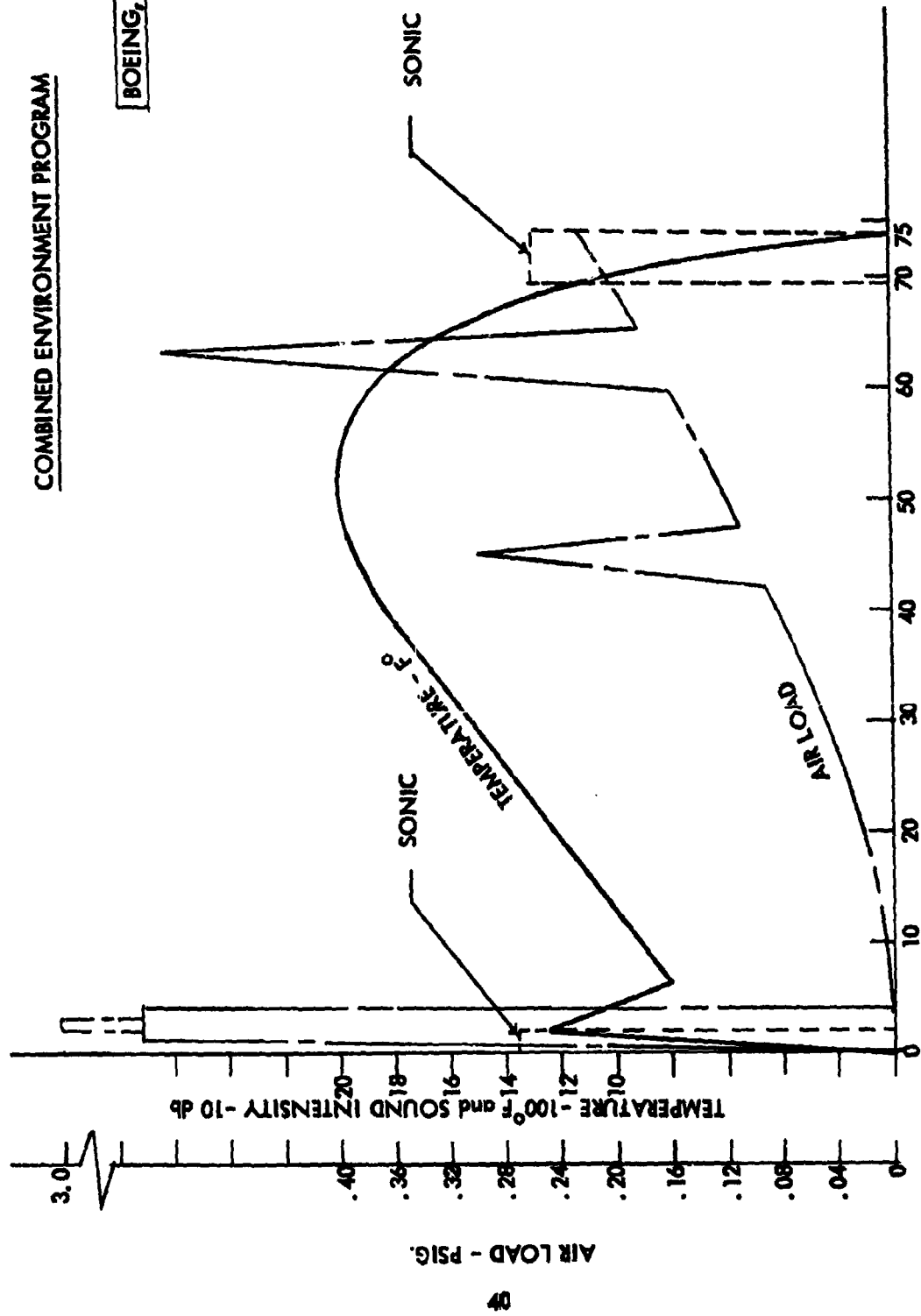
When the facility was built in 1951, the cost which includes 3 sirens, the building (See Figure III A-1) the test cells, air compressors, and some instrumentation was \$425,000.

Test program costs are based on engineering and shop hour requirements for the particular test objective. The cost per man hour (including overhead and amortization of the sonic facility) plus the material and specimen cost will then give the total cost of the program.

A recent sonic program involving development of corrugated hot structures which evaluated three different materials and three configurations for a total of 15 panels cost approximately \$75,000.00 and extended over a one month period. This was a cost for a complete program including designing, building and testing the panels.

7. COMBINED ENVIRONMENTAL TESTING

The sonic facility also has the capability of performing combined environmental tests. These tests consist of combined sound - high temperature, sound - low temperature, and sound - static pressure tests. These tests are conducted on a joint responsibility basis with other Boeing laboratories who specialize in the particular environment required. Combined environmental tests are planned and conducted on an individual basis with the necessary equipment and jigs procured and/or designed for the particular test. Tests have been performed combining sound with temperature ranges of from -450° F to 2000° F. Combined sound and static pressure tests have been run to 3 psi on the specimen.



TYPICAL COMBINED ENVIRONMENT PROGRAM

FIGURE III A-14

8. BIBLIOGRAPHY OF RELATED REPORTS

JOHNSON, D., "Sonic Tests of Corrugated Hot Structures Panels", Test Progress Report SLSL-59-8, December 22, 1959

JOHNSON, D. L., "Sonic Tests of Corrugated Hot Structures Panels", Test Progress Report SLSL-59-5, December 8, 1959

JOHNSON, D. L., "Sonic Tests of Corrugated Hot Structures Panels", Test Progress Report SLSL-60-1, January 7, 1959

JOHNSON, D. L., "Sonic Test of Stainless Steel Honeycomb Panel", Test Progress Report SLSL-60-10, August 5, 1960

JOHNSON, D. L., "Development of a Progressive Wave Sonic Test Chamber", Test Progress Report SLSL 59-3, November 17, 1959

LaCROIX, CHARLES, "Combined Environment Test of M-252 Corrugated DS-1 Panel Test Progress Report SLVL 59-73, April 29, 1959

BAKER, ARNOLD, "Environmental Tests of M-252 Insulated Panel", Test Progress Report SLVL 59-81, April 28, 1959

HEPLER, A. K., "Sonic Testing Summary Wing Trailing Edge and Flap Structure" Document No. D-17774, March 31, 1956

LEARY, R. E., "Sonic Test of Wing Trailing Edge Structure (ELT 185-2)", Test No. T2-1155, June 27, 1957

LIN, Y. K., "Stresses in Continuous Skin-Stiffener Panels Under Random Loading", The Journal of Aero/Space Sciences, August 1960

EDSON, J. R., "Sonic Structural Fatigue Summary - B-52B through B-52G Aircraft" Document No. D2-2910, October 31, 1958

KAMM, A. J., and FULLER, J. R., "Evaluation of Sonic Fatigue on KC-135 Fuselage Skin Panels with External Circumferential Straps", January 31, 1959

OLSON, BRUCE V., "Sonic Test Facility Operations Manual", April 21, 1959

JOHNSON, D. L., "Acoustic Noise Test of Instrumentation Compartment Wiring Installation" Phase I, Test Progress Report SLSL-60-7, July 19, 1960

ANONYMOUS "Sonic Test Facility", this is an undated description of their facilities.

III-B.

**THE BOEING COMPANY
WICHITA DIVISION
WICHITA, KANSAS**

1. GENERAL DESCRIPTION

Boeing, Wichita, operates two sonic facilities:

- (1) 170 db siren test installation
- (2) Sonic wing test facility

The facilities were built to carry out work to correct sonic fatigue failures that were exhibited in the B-47 and B-52 aircraft.

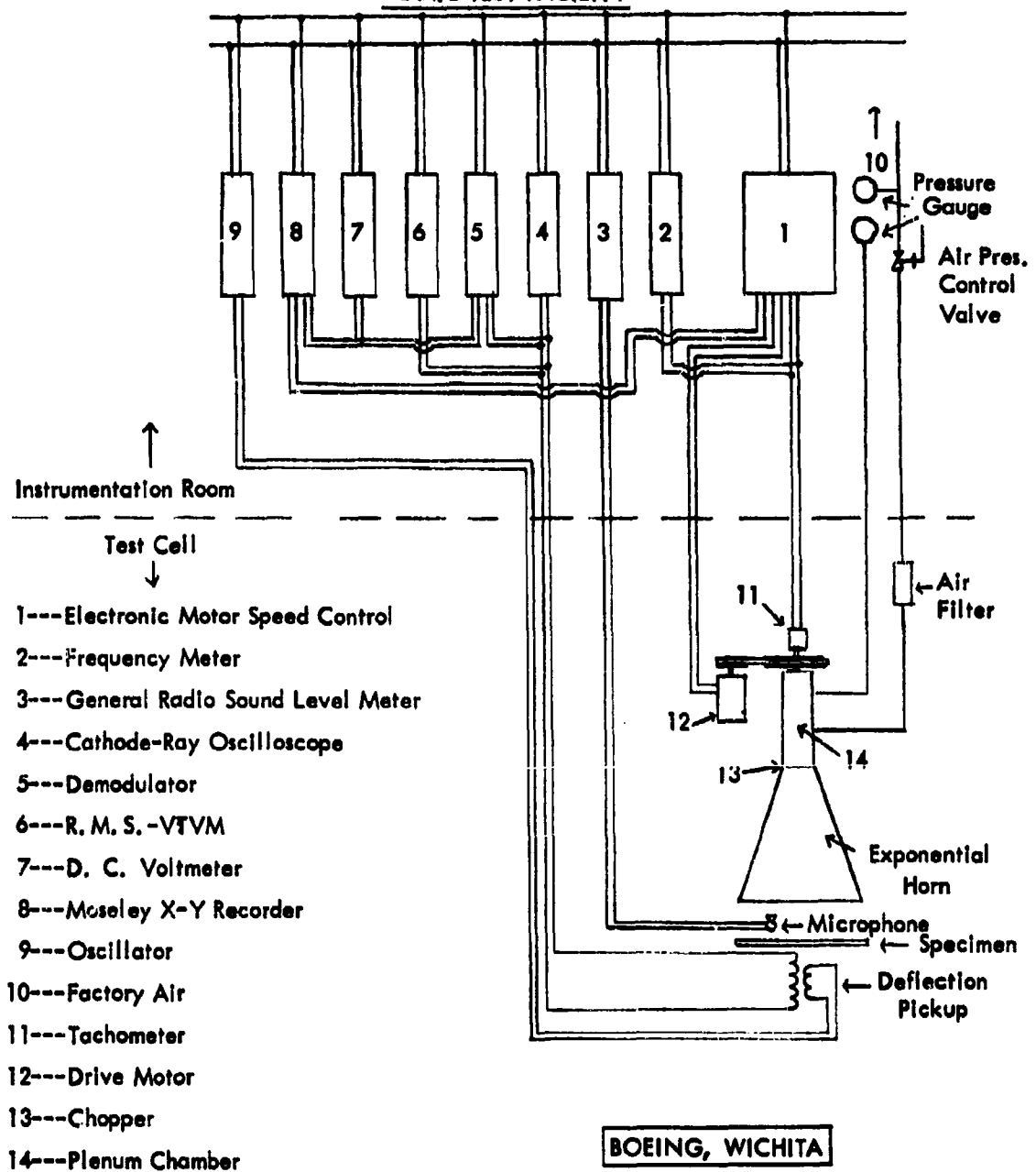
(a) Siren Facility

The siren facility consists of a test chamber, siren, air supply, and control system, and has associated with it its own measuring devices and recording equipment. Figure III B-1 is a block diagram of the facility which shows the relationships of the various components. Figure III B-2 is a photograph of the siren and horn placed in the chamber with a specimen. A factory air supply (1200 cfm and 120 psi) maintains 1200 cfm at 45 psi in the plenum chamber of the siren. The area at the mouth of the horn is 9 square feet. The dimensions of the test cell are 10', 8-1/2 inches long by 8', 5-1/2" wide by 6', 11" high. Walls with two 1" layers of mineral wool partitioned by plywood plus a covering of coritane, and an absorbent floor covered with a steel grating have been installed to reduce standing waves in the chamber.

(b) Sonic Wing Facility

The sonic wing test facility was developed primarily to provide a test capability for evaluation of components and structures installed on the B-52 aircraft wing. Four J57-P43W engines mounted on a simulated B-52 wing are the principal components. Figure III B-3 is a photograph of this installation.

BLOCK DIAGRAM SONIC TEST FACILITY



BLOCK DIAGRAM SONIC TEST FACILITY

FIGURE III B-1



HIGH INTENSITY SIREN

BOEING, WICHITA

FIGURE III B-2

BOEING, WICHITA



SONIC WING FACILITY

FIGURE III B-3

2. TYPES OF SOUND SOURCES

(a) Discrete Siren

The discrete frequency siren operates in the frequency range, 130 cps to 2500 cps. Figure III B-4 is a plot showing the siren output (up to 500 cps) 3" from the horn. The actual siren design is similar to that of Boeing, Seattle. It is electrically driven and the frequency is electronically controlled. The sound pressure level is controlled by air pressure supplied to the plenum chamber and small variations in sound pressure level over the frequency range are attributed to variations of efficiency of the horn at different frequencies.

Sound pressure level measurements made approximately 3" from the mouth of the horn indicate a variation of 3 db over the 9 square foot area without a specimen in place. The output of the siren over the 130 cps to 2500 cps frequency range is reported by Boeing to be 170 db (plus or minus 5 db).

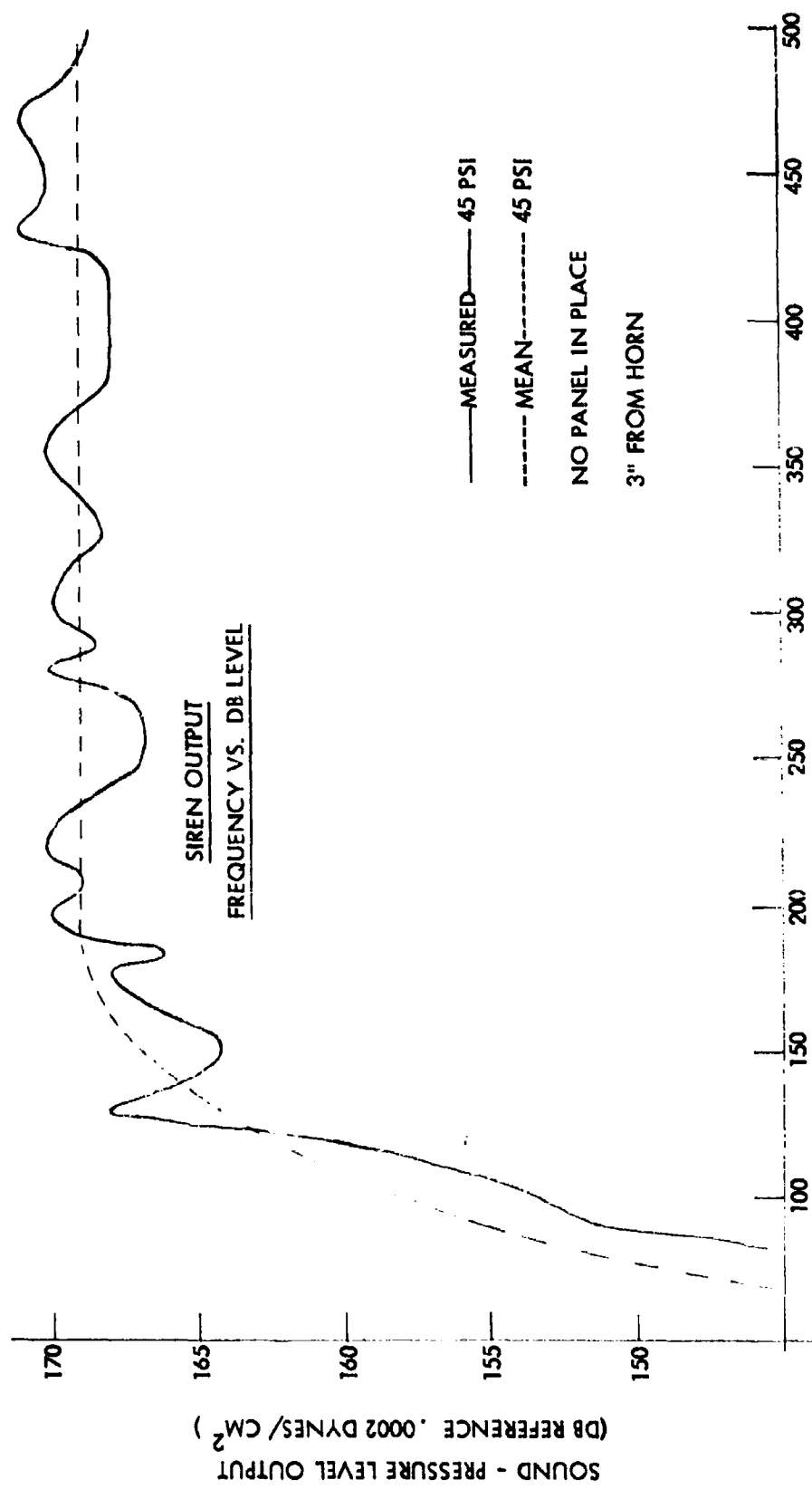
Figure III B-5 is a graph of frequency versus rms sound pressure and shows the harmonic content of the siren when it is running at a fundamental frequency of approximately 200 cps.

(b) Jet Engines (Sonic Wing)

Four jet engines mounted on a simulated B-52 wing provide an overall sound pressure level of approximately 165 db. The sound source provided by the jet engines approximates the operating environment to which the equipment and structures are subjected.

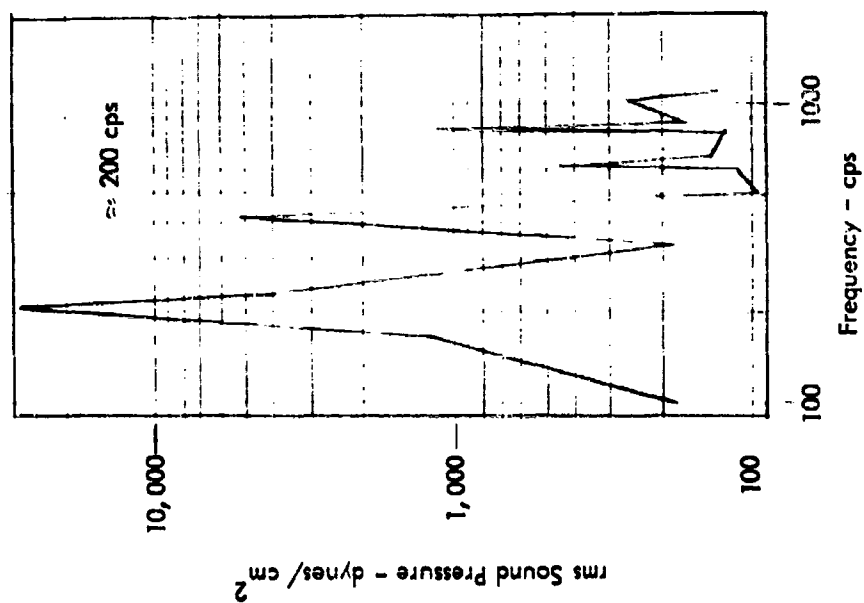
3. TEST METHODS AND SPECIMEN ARRANGEMENT

The sound pressure level that is assumed to act on the specimen during the test is determined prior to placing the specimen in the test chamber. Calibration curves which relate the SPL in the test chamber to the air pressure in the siren plenum chamber (and the siren speed) are prepared without the specimen in place. At the time of test the specimen is positioned in the chamber, the speed and air pressure of



FREQUENCY (CPS)
SIREN OUTPUT FREQUENCY VS. DB LEVEL
BOEING, WICHITA

FIGURE III B-4



Sonic Horn Test Facility
 Sound Pressure Level: 157 db
 Transducer: microphone
 Location: 4" in front of the horn,
 at the edge of panel

BOEING, WICHITA

INDICATION OF HARMONIC CONTENT

FIGURE III B-5

the siren are set, and the SPL to which the specimen is exposed is inferred from the calibration curve.

The specimens are placed in front of the horn so as to be at normal incidence to the sound and the resonant frequency of the particular panel being tested is determined by sweeping the frequency range at reduced levels.

When possible, actual specimens are taken from production to be used for testing. In those cases where the structure is in an R and D stage, specimens are specially made for testing. Dimensions of a specimen are limited to the horn area which is 9 square feet.

Failure of the specimen is detected by changes in resonant frequency or in amplitude. The specimen is not considered failed until visual inspection reveals a fatigue crack or structural failure. All specimens are inspected before testing and any unusual features are noted.

In the sonic wing facility, the main structural specimen is the wing itself. Any specimen, other than components of the wing, is oriented parallel to the direction of the jet stream. The sizes of these specimens are full scale. Specimen response is generally determined with accelerometers and strain gages, and the strain gages are located at those points where engineering judgement indicates the greatest response is likely to occur.

4. INSTRUMENTATION AND DATA ACQUISITION

Figure 111 B-6 is a block diagram of the instrumentation used for making noise and specimen response measurements for both the siren test facility and the sonic wing facility. The sonic wing facility also has the usual instrumentation for measuring temperature, pressure, and other variables necessary for the control and operation of jet engines.

(a) Noise Measurement

Sound pressure level is measured with Altec M-14 high intensity microphone

systems and General Radio sound level meters. Oscillographs, oscilloscopes, tape recorders, and automatic plotters are used to analyze the outputs of the microphones. This measurement system is supplemented by the services of the Acoustics and Electro-Physics Group's Laboratory. These services include the determination of acoustic environment required for testing, microphone and system calibration, data readout and reduction, and data analysis and presentation.

in the sonic wing facility, the high intensity microphones are equipped with heat sinks for high temperature areas. In addition, the facility has available FM magnetic tape recording systems for acoustic and vibration measurements, oscillograph recording systems, panoramic spectrum analyzers, various vibration transducers, temperature recording systems, and pressure transducer systems. The instrumentation that is used in conjunction with this facility is housed in a 900 square foot acoustically treated operations control and instrumentation building.

(b) Response Measurement

Specimen response in the siren facility is measured with proximity pick-ups and/or strain gages. Observation of the specimen is accomplished by the use of a General Radio Type 631-BL Strobe light. Specimen response can be recorded with an X-Y recorder, tape recorders, or oscillographs.

The proximity pick-up is an air core transformer. The secondary is tuned through the primary with an audio frequency oscillator. The output voltage of the secondary varies with the change in coupling caused by the movement of the specimen. This voltage is calibrated to indicate specimen deflection on the cathode ray oscilloscope, or is demodulated and recorded on an X-Y recorder. A movement of a specimen when it is close to the transformer (within 1 inch distance) detunes the transformer by changing the flux linkage between the primary and the secondary. This in turn changes the output voltage of the secondary. The instruments are calibrated to record or observe

deflections within plus or minus one hundredth of an inch.

5. INTERPRETATION OF DATA

The main purpose of the test programs at Boeing, Wichita, is to establish proof of the integrity of a new design under intense noise loadings. The facilities are also used to conduct tests for comparing and evaluating panels of an experimental nature. The siren itself is considered a tool used by the structural design personnel to evaluate the sonic fatigue resistance of proposed configurations.

Panel life tests using the siren are set up arbitrarily to gain qualitative information on the relative merits of various specimens. In the sonic wing facility, the testing is done by running the engines at maximum rated power settings for the number of hours that maximum power would be used during the career of the plane (or perhaps slightly longer).

Tests are summarized by describing; (1) specimen excitation frequency and resonant mode shapes, (2) specimen displacement, (3) sound pressure level in db, and (4) time-to-failure of the specimen. The index of severity of a test is based upon the sound pressure level to which it is exposed and the index of fatigue life is time to failure.

No data has been used in evaluation of current cumulative fatigue theories or sonic fatigue prediction techniques. Since it is assumed that the test specimen response is extremely complex, Boeing, Wichita, has not determined or established any analytical procedures which it considers satisfactory for use in sonic fatigue design. No studies have been conducted to compare sonic fatigue test results with service life in actual environments.

6. TIME AND COSTS

The cost of a test specimen varies with the complexity of the structure and the materials used. The costs therefore vary between \$25.00 and \$1000.

The approximate cost of the siren system is \$20,000. This does not include the air supply system since factory air is used. The estimated operating cost of the

facility is \$25.00 per hour. For siren testing, a minimum of four panels of each configuration is considered necessary in order to establish reliable data. The average time for a test program such as this is approximately 100 hours of actual testing and 50 hours for reports and data reduction, and it is estimated that the total cost of a typical test program is \$2750.00, not including cost of specimens.

It is estimated that the cost for operating the sonic wing facility is roughly \$30,000.00 per hour of testing. This estimate is based on a test previously conducted. It should be noted, of course, that when a major sonic test program is in progress, many smaller programs can be run in conjunction with it so that the unit cost per test is greatly reduced.

7. COMBINED ENVIRONMENT TESTING

At the present time, no other tests are being performed in combination with sonic fatigue testing at Boeing, Wichita.

8. BIBLIOGRAPHY OF RELATED REPORTS

MORGAN, J., Boeing Airplane Company, Wichita, Kansas, "B-52G Half Wing Sonic Test", Document No. D3-1850 dated 3/31/60

This is a detailed report describing the tests performed using the half wing sonic facility.

There are several interim reports that have been published which describe some of these tests as they were carried on throughout the program. There are also several reports that have originated at the Seattle Division that are related to testing of the B-52 aircraft. These reports are not included since the salient features of the facility and pertinent tests are adequately discussed in the above document.

III-C. BOLT BERANEK AND NEWMAN, INC.
CAMBRIDGE, MASSACHUSETTS

1. GENERAL DESCRIPTION

The facility employs two hydraulically driven sirens placed at right angles to one another and discharging into a duct which has a one square foot cross-section. The siren which is coaxial with the duct is 24" in diameter and produces an approximately pure tone in the range 50 to 2000 cycles/second, while the siren which is perpendicular to the duct is 12" in diameter and produces a tone in the range 500 to 10,000 cycles/second.

The duct is constructed in such a way that a steel plate can be inserted so as to bisect the angle between the sirens. This plate (which can be perforated or solid) acts as an acoustic mirror and reflects the high frequency signal down the duct; the perforated plate, which passes the low frequency, is used when both sirens are required.

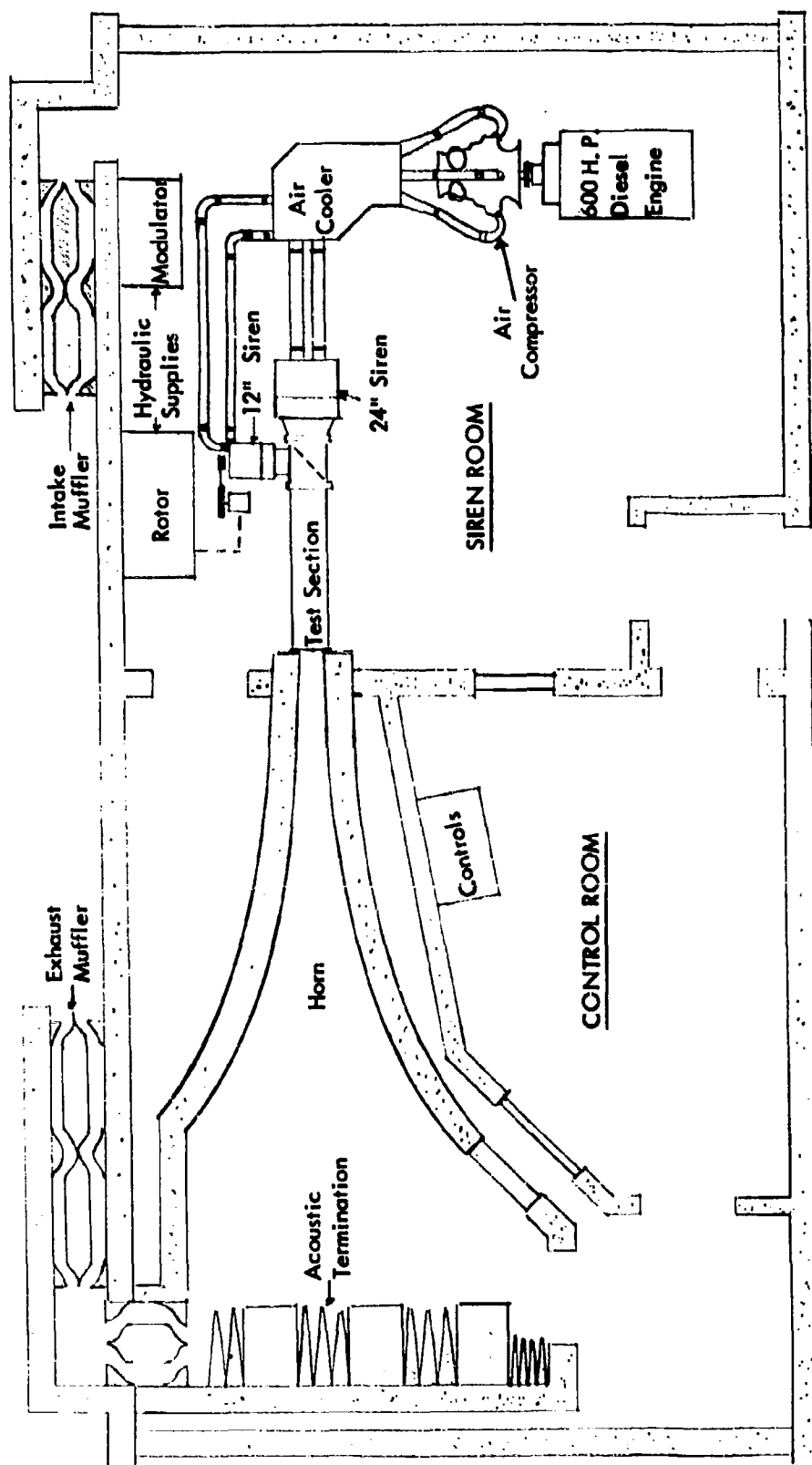
The duct is coupled to a large, concrete horn which terminates in a room some 500 cu. ft. in volume, this room has a non-reflecting surface (consisting of removable wedges) opposite the horn.

Air for the sirens is provided by a supercharger (from an obsolete aircraft engine) which is driven by a 600 HP diesel engine.

Figure III C-1 shows the plan view of the sonic facility.

2. TYPES OF SOUND SOURCES

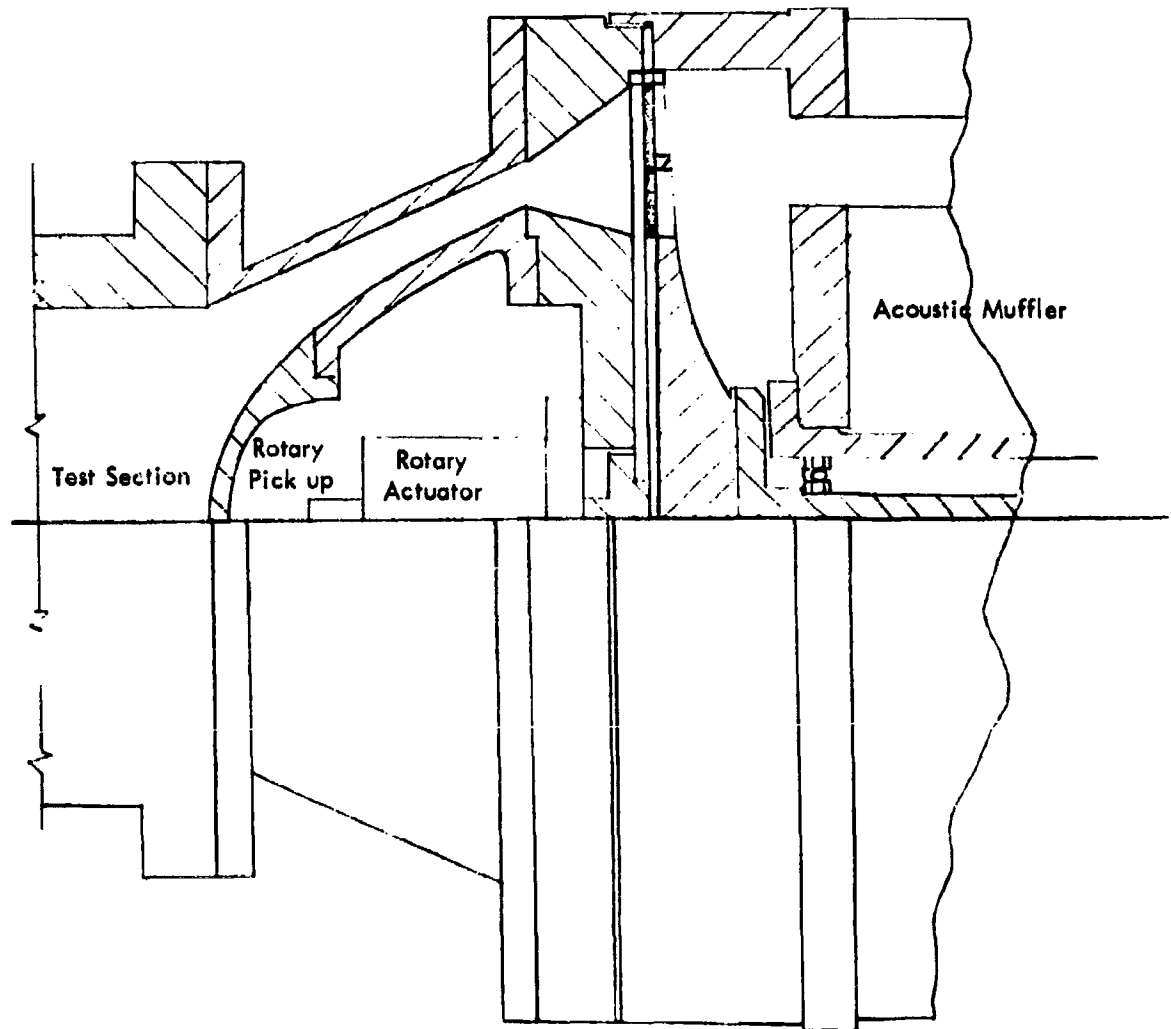
Figure III C-2 shows a cross-section view of the low frequency siren, and the cross-section of the high frequency siren is the same except for size and slight changes in detail. One of the main objectives in this design of the sirens was to obtain signals of as nearly sinusoidal character as possible. This was accomplished by shaping of the rotor ports. In addition to the rotor there is another perforated disc, which



PLAN VIEW OF SONIC FACILITY

FIGURE III C-1

BOLT BERANEK and NEWMAN INC.



CROSS SECTION OF LOW FREQUENCY 24 INCH SIREN

FIGURE III C-2

although free to rotate, is simply caused to oscillate through a maximum excursion of 8° (the angular distance between the stator ports). This disc, by altering the effective area of the stator ports, modulates the amplitude of the siren signal. In various fixed positions this disc may also be used to control the output of the sirens. Figure III C-3 shows the shapes of the ports of the rotor, stator, and modulator. Hydraulic motors are used to drive the rotor and modulator and, by programming the flow valves, a variety of amplitudes and frequencies can be obtained.

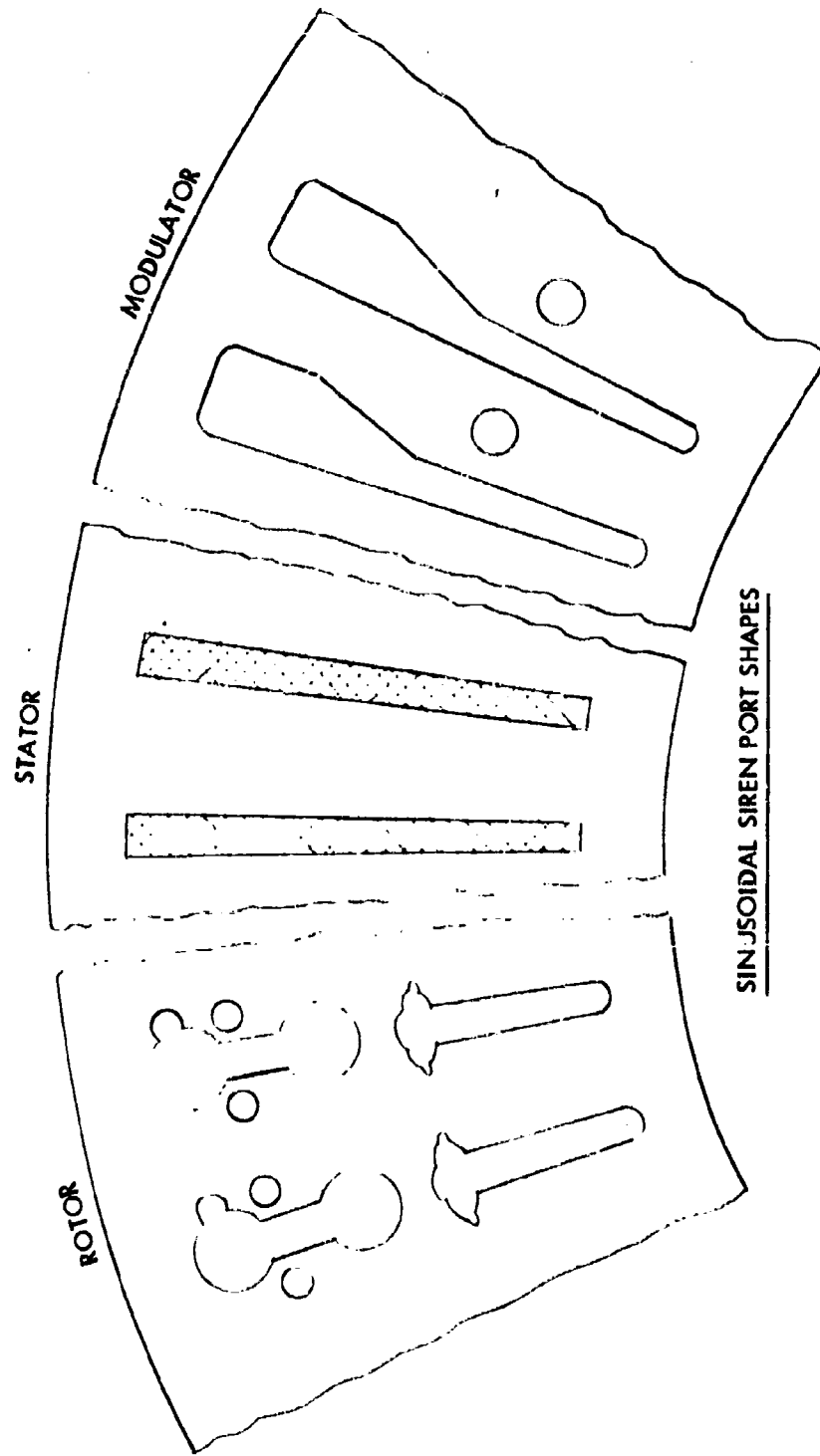
In the 1 square foot test section, sound pressure levels of 160 db are obtained with the diesel engine idling and 174 db with the engine running at full power; this latter figure corresponds to an acoustic radiated power of 22,000 watts. Figures III C-4 and III C-5 are plots of the outputs of the low and high frequency sirens. Figure III C-6 is a plot showing the variation in sound pressure level with fixed positions of the modulator plate. Figure III C-7 shows the harmonic content at various frequencies of a 12" prototype siren. Harmonic content measurements are being made on the large 24" siren, but the information was not available in time for this report. The efficiency of the sirens varies between 10% and 20% depending on the frequency and sound power output (10% at maximum sound power output).

When sound pressure level measurements were made at various transverse positions across the 7 foot square horn in the termination section, it was found that a reasonably uniform distribution was obtained below 1000 cycles. Above this frequency, the distribution was quite non-uniform and this is attributed to the occurrence of cross modes.

The presence of cross modes in the 1 square foot section (occurring at the upper end of the frequency range) produced large fluctuations in sound pressure level measured in the duct.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

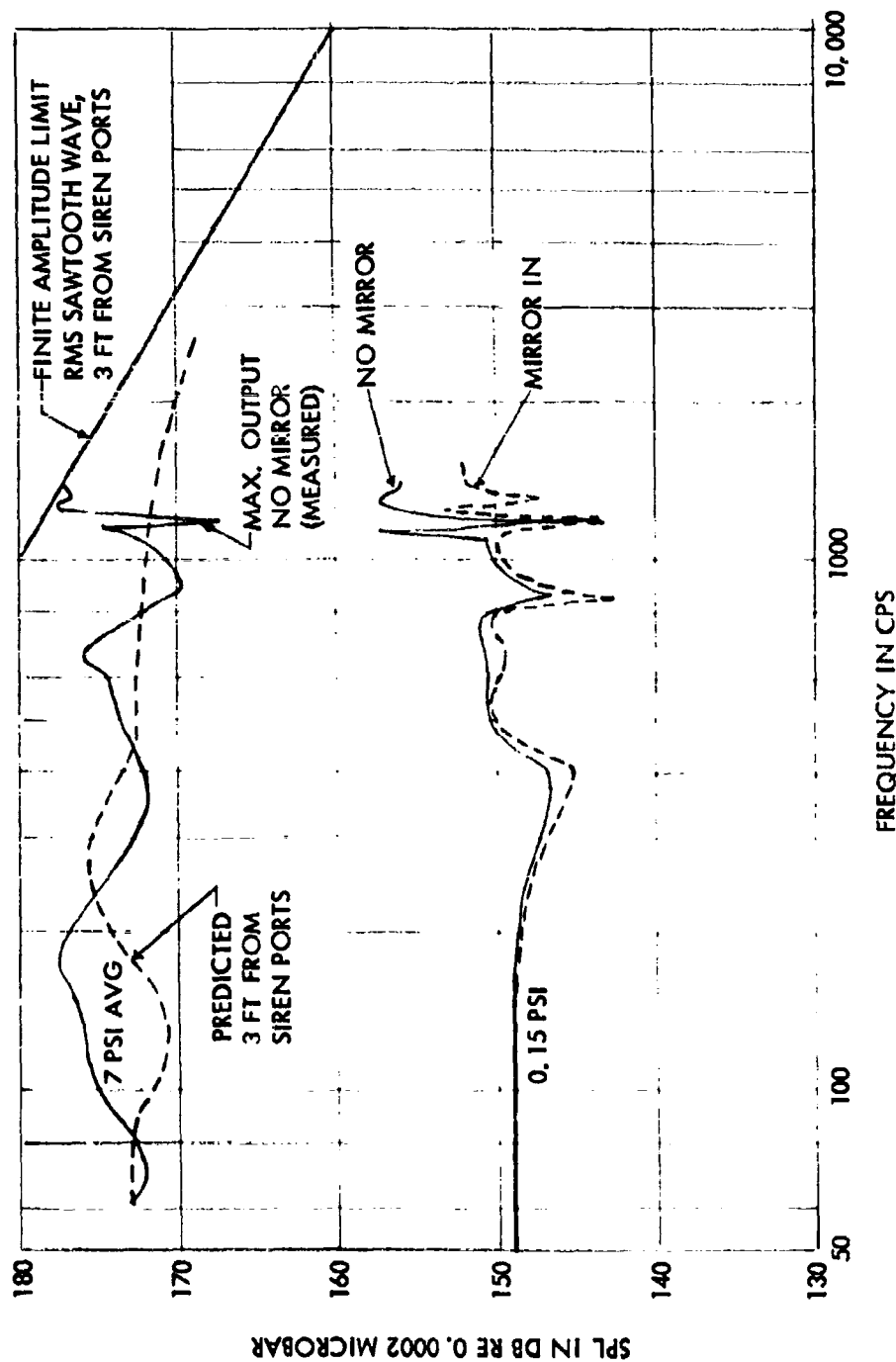
The 1 sq. ft. test section has a removable wall which can be replaced by



BOLT BERANEK AND NEWMAN INC.

SINUSOIDAL SIREN PORT SHAPES

FIGURE III C-3



FREQUENCY RESPONSE OF LOW FREQUENCY SIREN IN
1 SQ. FT TEST SECTION, 3 FT FROM SIREN PORTS

FIGURE III C-4

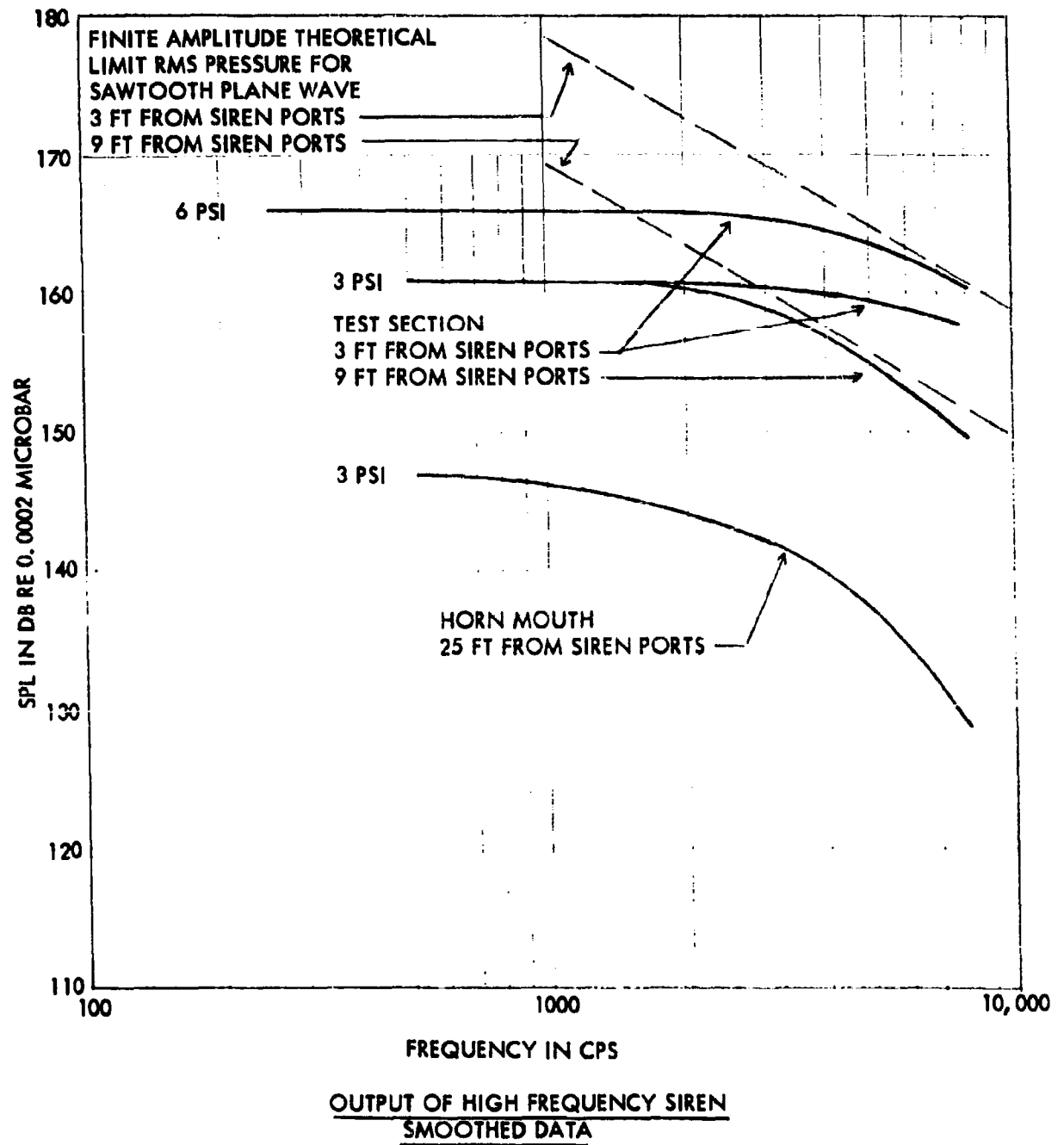
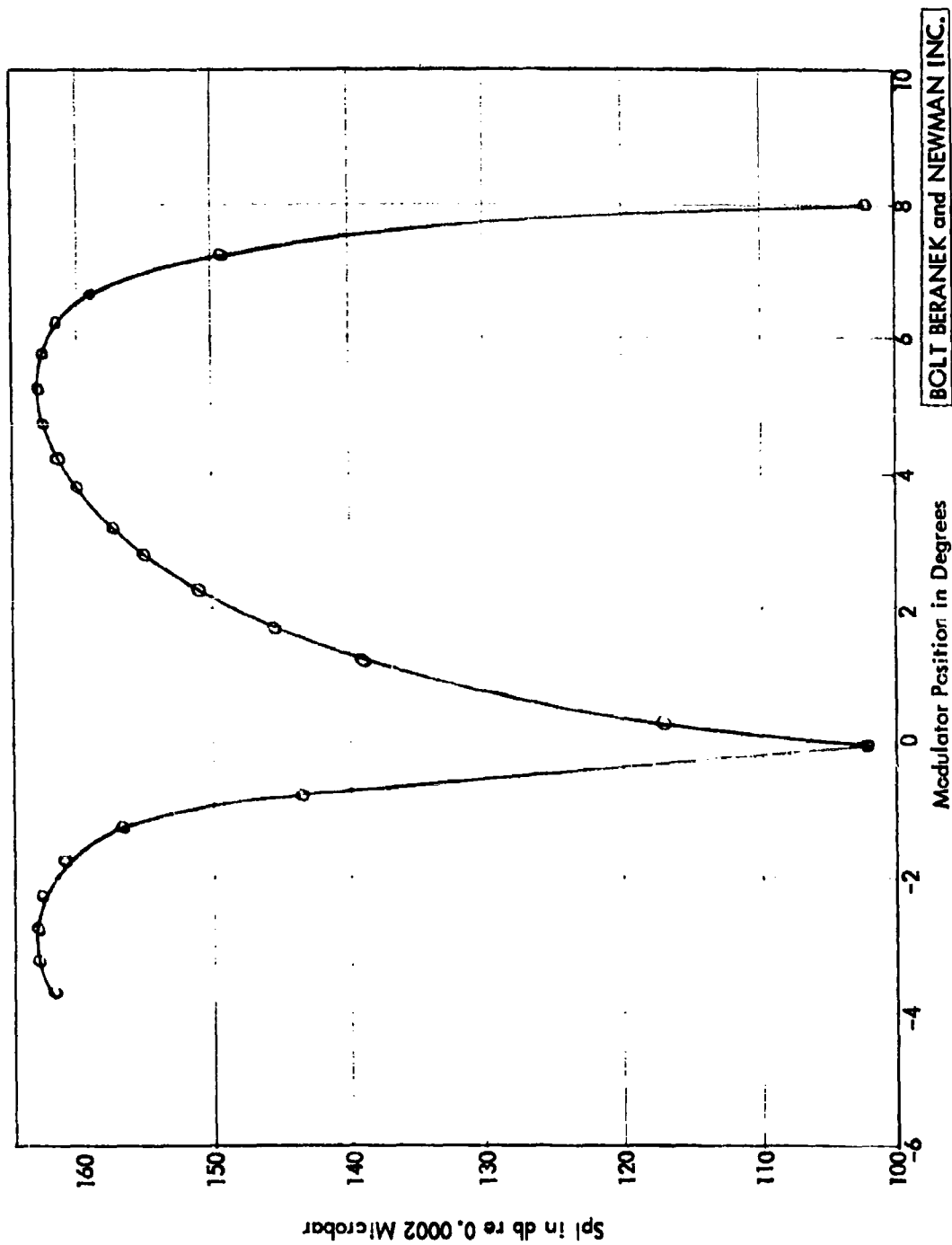


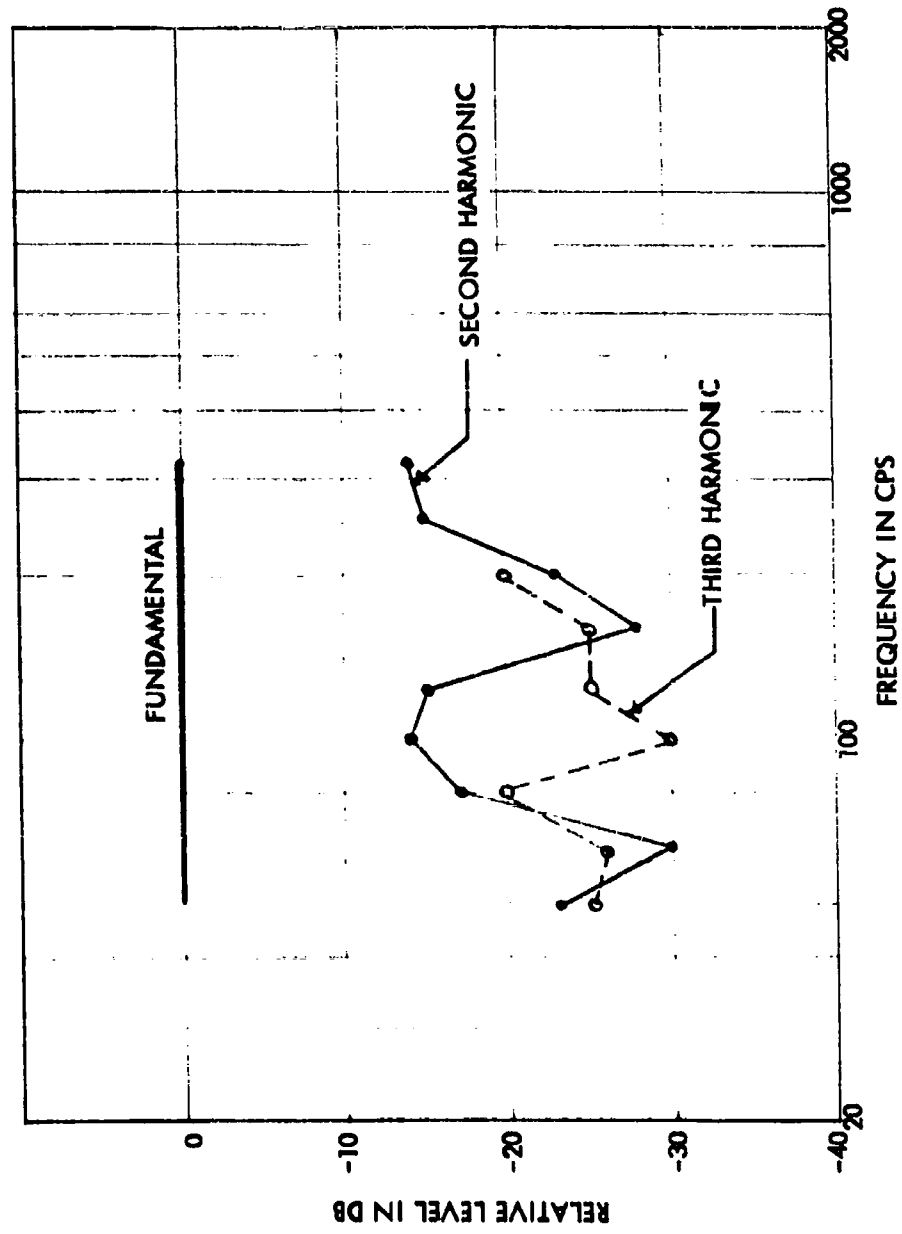
FIGURE III C-5



BOLT BERANEK and NEWMAN INC.

SIREN OUTPUT VS. MODULATOR POSITION

FIGURE III C-6



HARMONIC COMPONENTS
12" LOW FREQUENCY SIREN (Prototype)

FIGURE III C-7

test panels varying in width from several inches to about 1 foot. Panels mounted in this way experience a progressive wave excitation.

For normal incidence testing, specimens can be mounted in the horn or in the termination chamber, the exact location being controlled largely by the size of the specimen.

The acoustic wedges on one wall of the termination chamber are removable. When these wedges are removed they expose a poured concrete wall 1 ft. thick and the chamber is then suitable for reverberant testing.

4. INSTRUMENTATION AND DATA ACQUISITION

Since this facility was not designed with the intention of carrying out routine testing there is no 'standard' instrumentation that can be described.

The facility was designed primarily as a research tool rather than a proof testing device; however, the design and construction of the sirens and the choice of layout of the facility served as design studies for the much larger testing establishment to be built at Wright Air Development Division.

The type of instrumentation used in the facility varies from test to test and depends upon the specific data required.

5. INTERPRETATION OF DATA

The types of programs carried out in the facility do not require, at the present time, methods of interpreting data in terms of the fatigue life of structures. Dr. Preston W. Smith, Jr. mentioned some fatigue research now being started that might require the use of the facility. Since these programs have just been started there was little to discuss, but it appears that the aim of much of the work will be to clarify the response mechanism of typical plates and strips that are exposed to plane progressive waves of modulated frequency and amplitude.

6. TIME AND COSTS

The construction cost for the facilities at Bolt Beranek and Newman, Inc.

was approximately \$215,000. This cost includes some detailed design, preparation of drawings, and supervision of construction. It is estimated that the actual cost to reproduce such a facility would be one-half to two-thirds of this cost depending upon the special requirements.

7. COMBINED ENVIRONMENT TESTING

No combined environmental testing has been performed in the facility and no special provisions have been made for such testing.

8. BIBLIOGRAPHY OF RELATED REPORTS

BOLT BERANEK AND NEWMAN, INC., Progress Reports on the combined contracts AF33(616)-5274 and AF(600)-35158

Report dated 8 July 1957

This report discusses (1) the preparation of a manual on acoustic noise and vibration in aircraft and missiles and (2) the program for studying various sound sources to be used in high intensity noise facilities for WADD.

Report dated 9 August 1957

This report includes:

- (a) Summary of information on available microphones for measurement of high intensity noise.
- (b) A review of some existing noise source facilities which are currently used for fatigue testing.
- (c) A discussion of finite amplitude distortion and shock wave formation which is a serious limiting effect upon the noise levels obtainable from a test facility.

Report dated 10 September 1957

This report has discussions of random vibrations, of the problem of mechanical vs. acoustical excitation, and periodic and random testing is included. The discussions are brief and indicate first thoughts on the above subjects.

Report dated 10 January 1958

This report includes a pertinent discussion of the sound source design as applied to the electronic component testing facility as well as the WADD large structural test facility. It also discusses physical considerations that influence the choice of a satisfactory siren system as well as the design of individual siren sources themselves.

Report dated 10 February 1958

This report discusses (a) factors that influence harmonic generation by a siren (steady and variable flow conditions, square wave generation, arbitrary

wave form) (b) conditions for sine wave generation (port area, operating pressure, and acoustic load) (c) harmonics arising from acoustic back pressure, and (d) trapezoidal area variation.

Report dated 4 April 1958

This report is devoted to a discussion of the theory, tests, and results obtained with a model siren. This model scale siren is one-twelfth the size of the siren to be used in the planned high intensity noise facility.

KAMPERMAN, GEORGE W. and STAFF, BOLT BERANEK AND NEWMAN, INC.,
"Design of the High Intensity Noise Facility", WADC TR 58-367, July 1958.

BBN Abstract

The facility described in this report is for performing research and development on the prevention of noise-induced fatigue damage of electronic equipment and structures. The facility has been designed primarily for progressive wave testing at high sound intensities. A special high intensity sound source has been developed and will cover the frequency range from 50 to 10,000 cps with a maximum acoustic power output of 22,000 watts. The sound source will be programmed to produce pure tones or narrow bands of noise having a controlled peak-to-rms ratio.

BBN Conclusion

The siren described here has demonstrated the principles involved in obtaining an amplitude modulated signal with controlled wave form. Because this siren is a prototype for a larger, 25 kw, unit which is now in the final design stages, the present siren has not been modified to obtain optimum performance characteristics. However, the design principles, and the experimental results reported here clearly indicate the directions to be followed to optimize the performance in the new design.

KAMPERMAN, ALLEN, SHARP, AND WILLIAMS, Bolt Beranek and Newman, Inc.,
"Performance of Intense Acoustic Facility for Flight Vehicle and Electronic Research", WADD TR 59-12, December 1959

BBN Abstract

A sonic failure research facility has been constructed for testing flight vehicle structures and electronic systems in the presence of high intensity

sound. The siren sound source will produce pure tones or narrow bands of noise throughout the frequency range from 50 to 10,000 cps with controlled amplitude modulation from 0 to 50 cps. The maximum acoustic power output is 22,000 w to produce a sound pressure level of approximately 174 db in the 1 ft. square progressive wave test section. This report discusses the performance of the facility.

**III-D. GENERAL DYNAMICS/CONVAIR
FORT WORTH, TEXAS**

1. GENERAL DESCRIPTION

Practically all of the sonic fatigue work done in the facilities at Fort Worth is related to the B-58 aircraft. The facilities include a siren test chamber and a jet engine test stand. The set-up for the siren has been recently modified to improve performance and efficiency of operation and these modifications are included in this description.

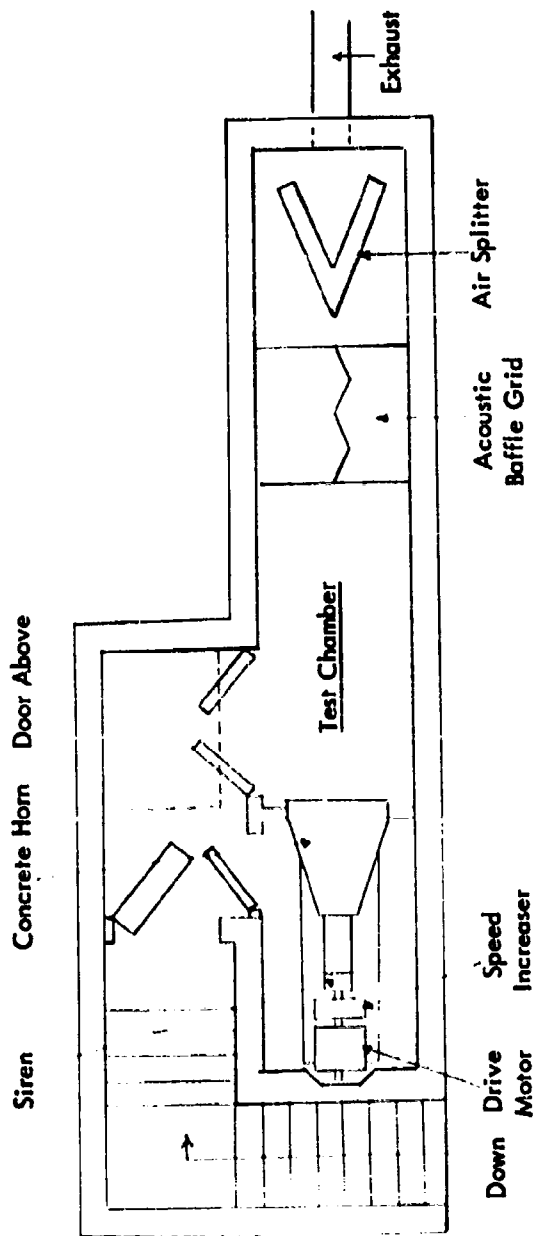
(a) Siren Facility

The siren facility (See Figure III D-1) consists of an underground enclosed room containing a discrete frequency siren, a drive motor, a plenum tank, and various control systems. The test chamber is separated from the siren room by a double wall. Figure III D-2 shows a specimen with its holder placed at normal incidence to the horn in the test chamber. Access to the installation is by way of a stairway for personnel and by an overhead removable slab for installation of heavy specimens. Directly above the siren system and test chamber is an enclosed shop and specimen handling area (See Figure III D-3). A control and instrumentation room adjoins the shop area and a data processing room is next to the control room.

The siren is driven by a 10 HP DC variable speed motor and normally consumes 150 lbs per minute of air from the plant air supply (a maximum of 450 lbs per minute is available). Automatic controls are provided to run the system.

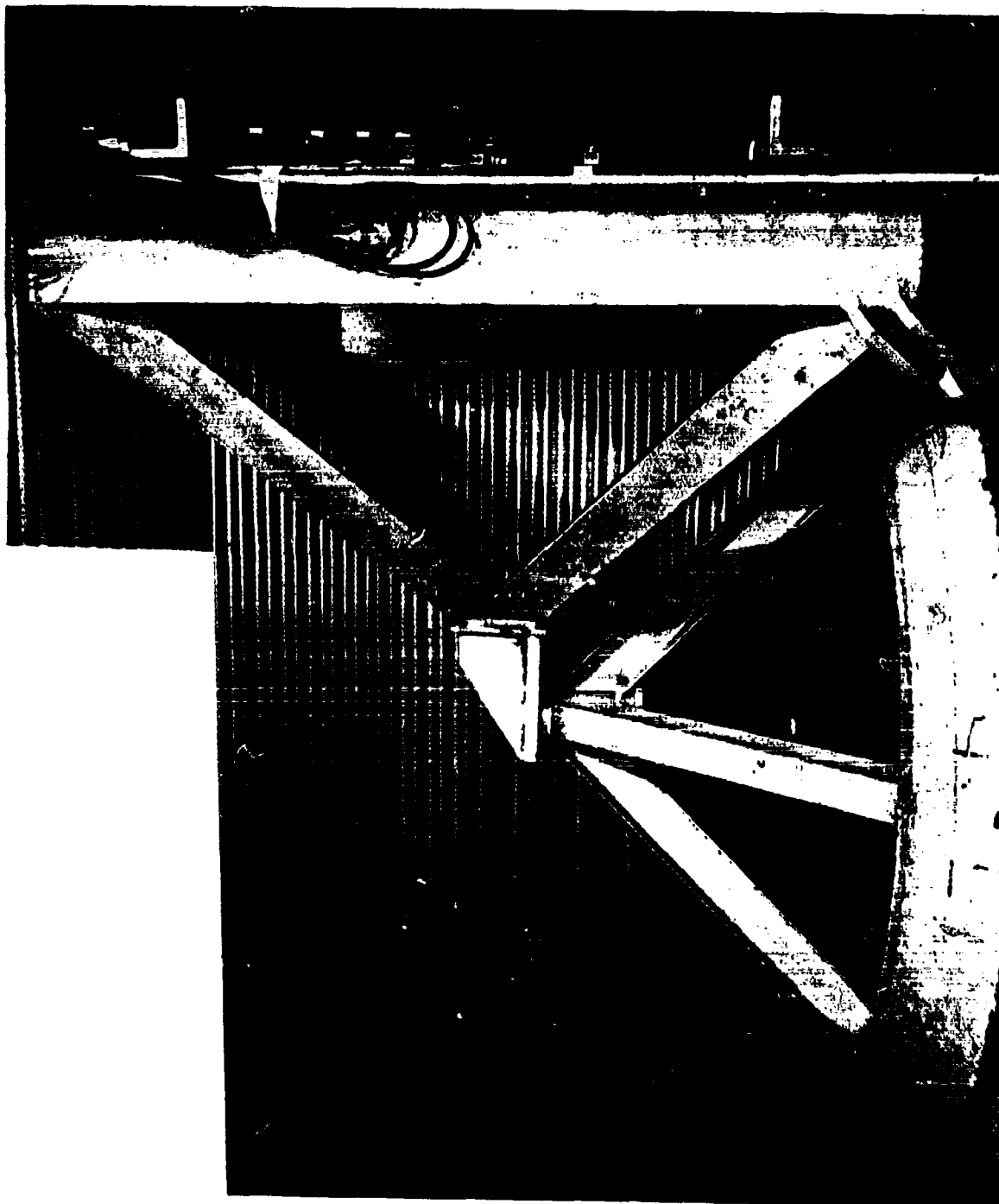
(b) Jet Engine Facility

Figure III D-4 is a sketch of the plan and side view of the jet engine test stand, and Figure III D-5 is a photograph of the jet engine test facility. The



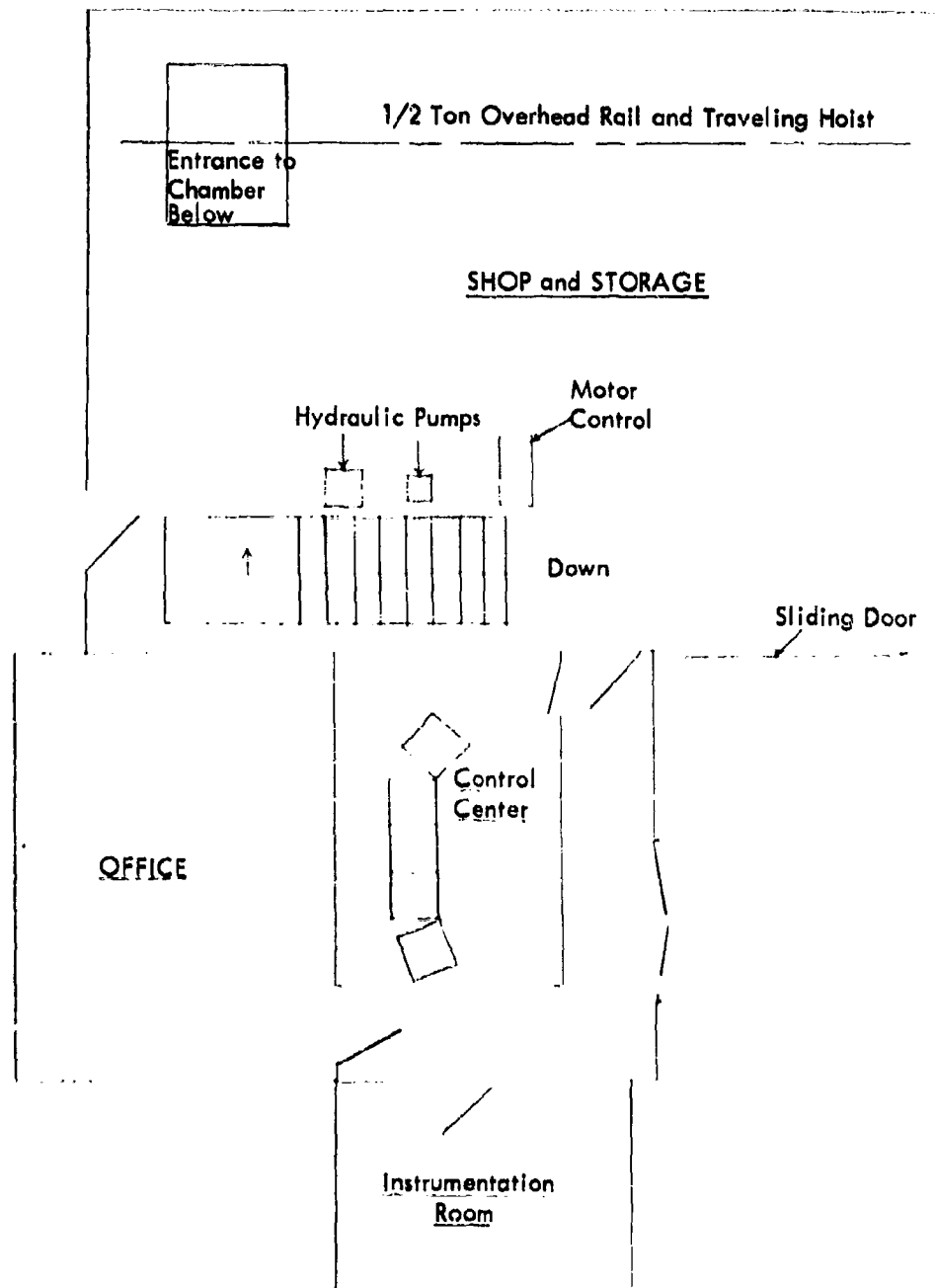
SIREN TEST FACILITY - UNDERGROUND PORTION

FIGURE III D-1



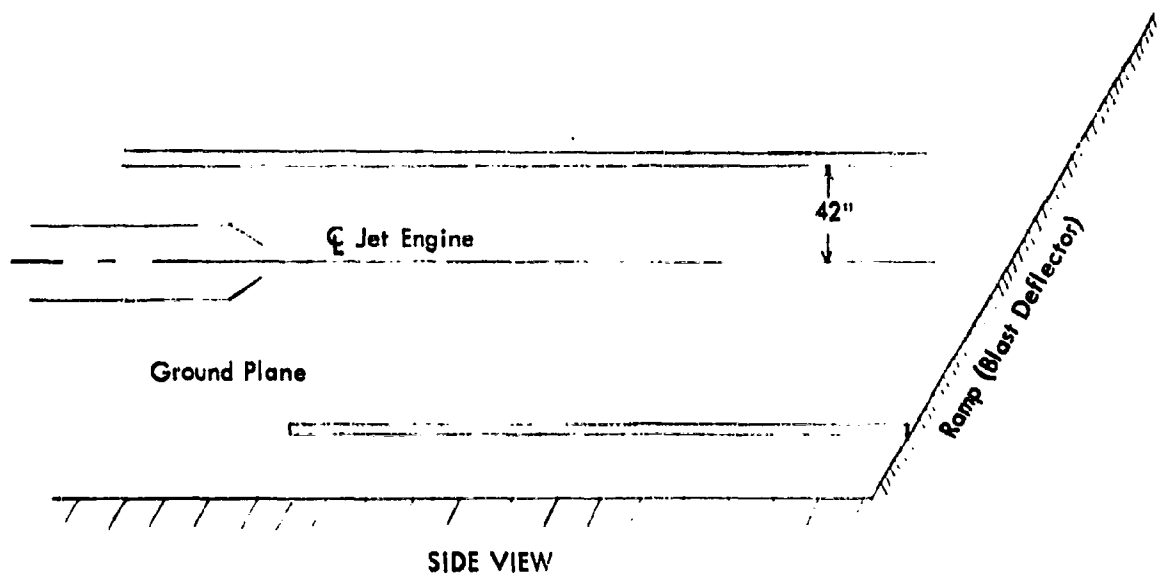
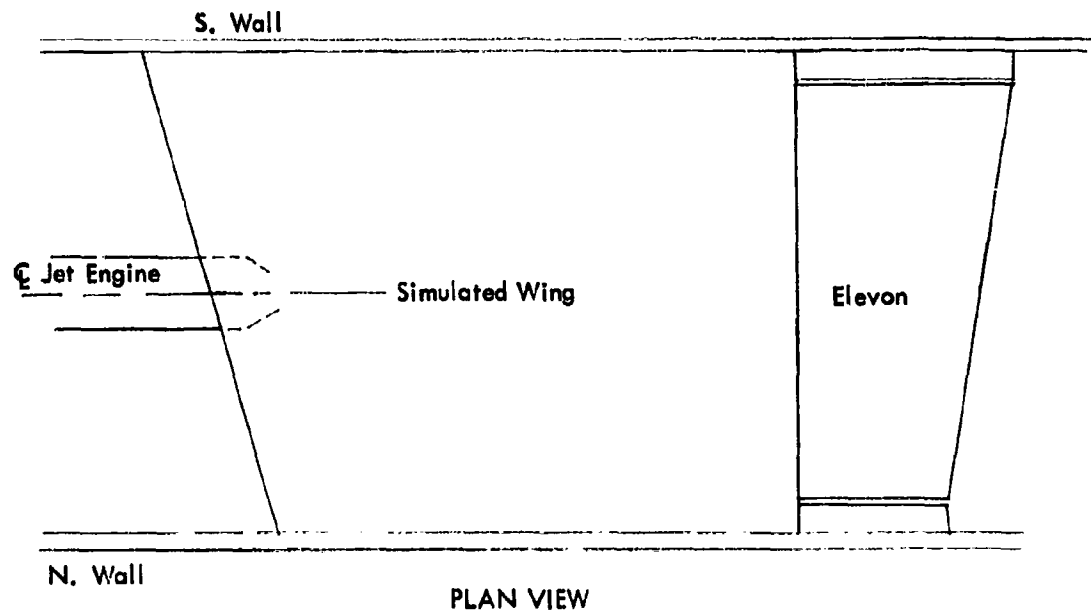
SPECIMEN AND ROTATING FRAME

FIGURE III D-2



SIREN TEST FACILITY - GROUND FLOOR

FIGURE III D-3



JET ENGINE TEST STAND
(SOUTH CELL)

FIGURE III D-4



JET ENGINE FACILITY

FIGURE III D-5

facility has used both a J79-1 and J79-5 jet engine, and as can be seen from the photograph, the test cell consists of concrete sidewalls, a sloping rear ramp, an open front, and a removable ground plane. The jet engine, and a simulated wing section and elevator are positioned to correspond to a B-58 inboard engine and wing arrangement.

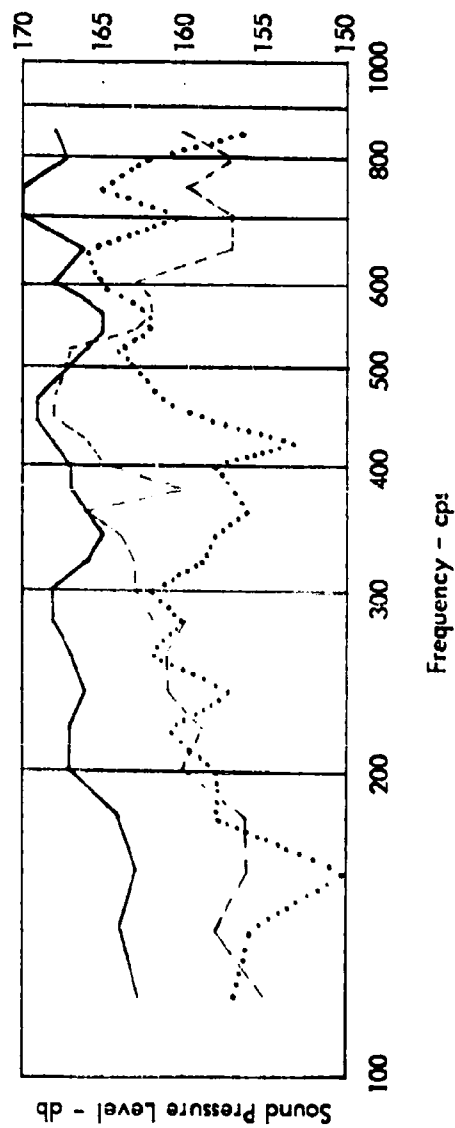
2. TYPES OF SOUND SOURCES

(a) Discrete Siren

The siren is a discrete frequency device with a frequency range of 100 to 2000 cps. Sound pressure levels in the test chamber which is approximately 6' wide, 6' high, and 12' long, vary with the location used for testing. Figure III D-6 shows the intensity vs. frequency of the siren with the microphone locations at 6", 6' and 11' along the center line from the siren face. When these measurements were made, the power output of the siren was continually adjusted so that a microphone centered at the face of the siren horn always read approximately 164 db. The actual maximum output of the siren is in excess of 170 db-6" from the horn in a bare chamber. At cross-sections of the chamber normal to the axis of the siren it is stated that the SPL varies by 3 to 5 db.

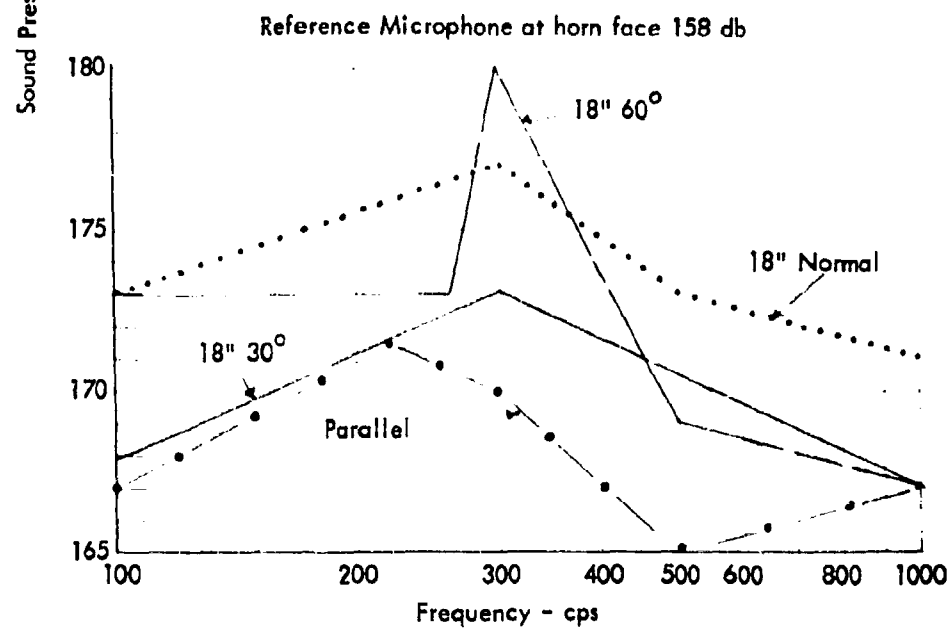
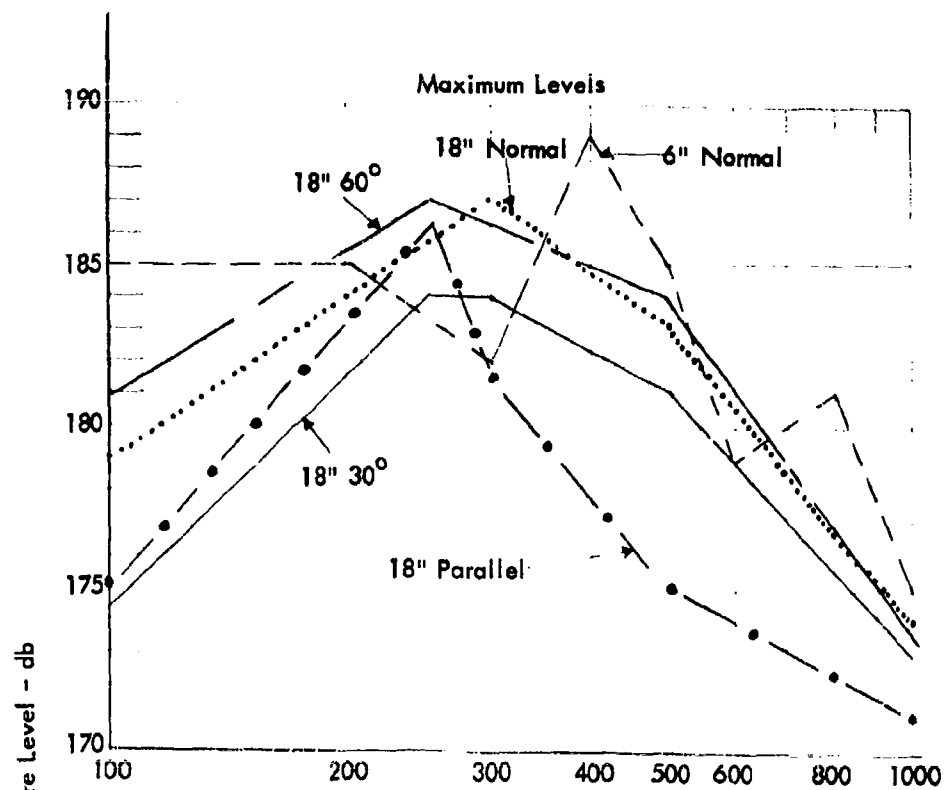
Figure III D-7 are plots of sound pressure level vs. frequency with a specimen located at normal incidence, at 60° to the axis of the sound stream, at 30° to the axis, and with a specimen parallel to the axis of the sound stream. The "inch" notation refers to the distance between the specimen and the horn face. The upper set of curves were all taken at maximum levels, and the lower set of curves were taken with a microphone located at the siren face reading 158 db as the tests were performed. Figures III D-8 and III D-9 are bar graphs showing the relative levels of the siren fundamental and harmonics in the bare chamber and in the chamber with specimens at various angles of incidence. Figures III D-10 and III D-11 show the same kind of bar graphs for measurements taken at various points along the center axis of the bare chamber. During the measurements, a reference microphone at the siren face read 158 db.

— Microphone 6" from horn face
 - - - Microphone 6' from horn face
 Microphone 11' from horn face
 Bare chamber measurements were made with
 reference microphone at horn face reading
 approximately 164 db at all times.



SOUND PRESSURE LEVEL VS. FREQUENCY
 IN BARE TEST CHAMBER

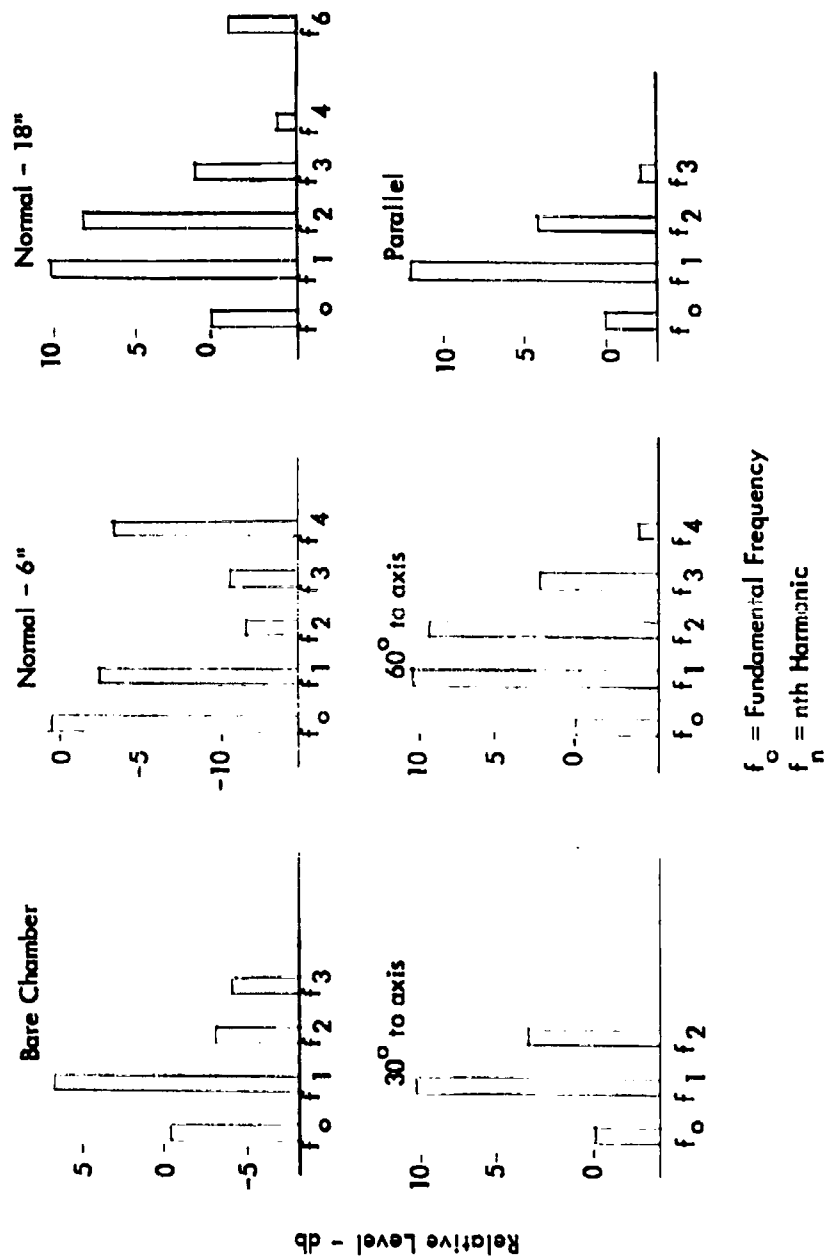
FIGURE III D-6



INTENSITY VS. FREQUENCIES ON PANEL FACE
AT VARIOUS ANGLES OF INCIDENCE

FIGURE III D-7

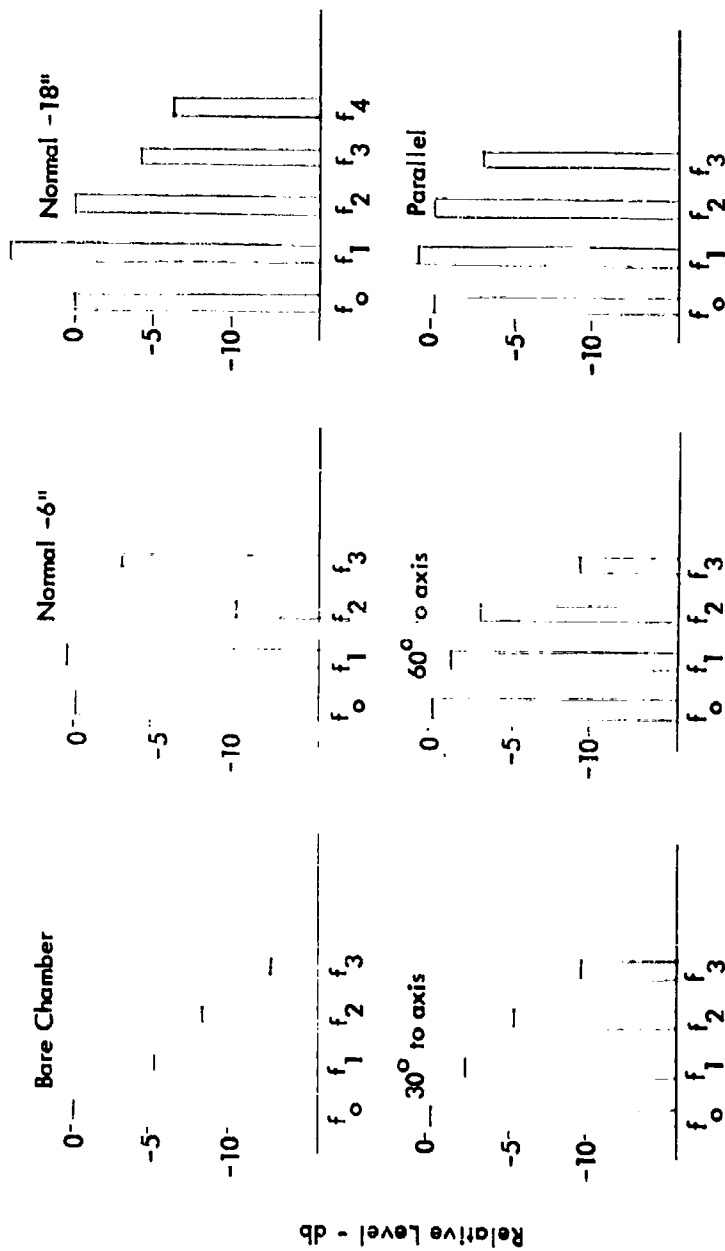
Fundamental Frequency = 100 cps - Reference Microphone Level at Horn Face = 158 db



RELATIVE LEVEL OF SIREN HARMONICS

FIGURE III D-8

Fundamental Frequency = 1000 cps - Reference Microphone Level at Horn Face = 158 db



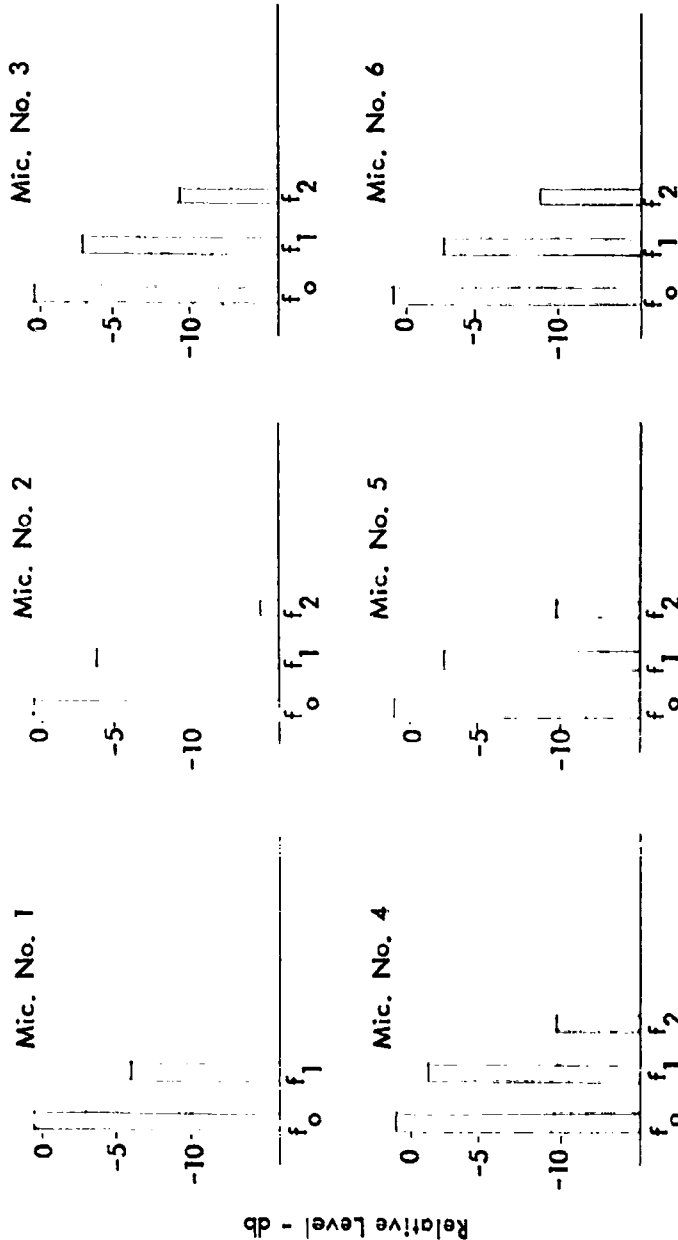
f_0 = Fundamental Frequency
 f_n = nth Harmonic

RELATIVE LEVEL OF SIREN HARMONICS

FIGURE III D-9

Fundamental Frequency = 120 cps - Reference Microphone Level at Horn Face = 158 db

Measurements Along the Central Axis of the Bare Chamber



f_0 = Fundamental Frequency

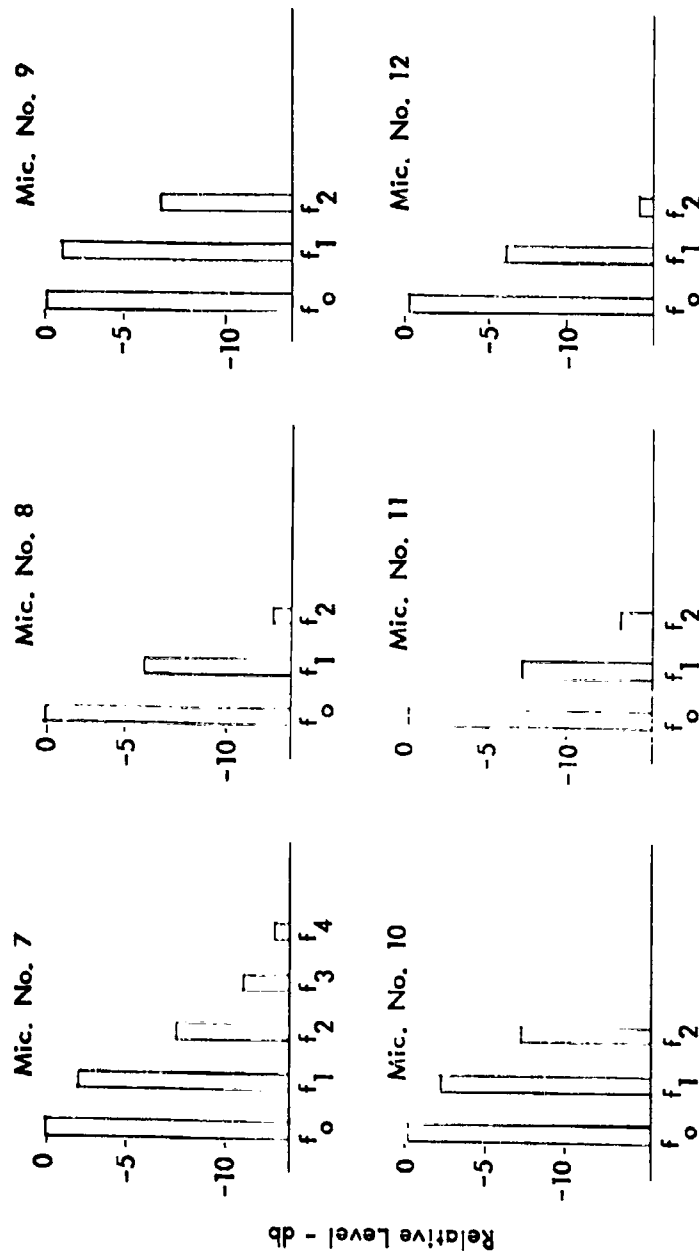
f_n = n'th Harmonic

RELATIVE LEVEL OF SIREN HARMONICS

FIGURE III D-10

Fundamental Frequency = 120 cps - Reference Microphone Level at Horn Face = 158 db

Measurements Along the Central Axis of the Bare Chamber



f_0 = Fundamental Frequency
 f_n = nth Harmonic

RELATIVE LEVEL OF SIREN HARMONICS

FIGURE III D-11

o

(b) Jet Engine

J79-1 and J79-5 jet engines have been used as noise sources in the jet engine test stand facility. The thrust according to General Electric specifications for these engines is 10,000 lbs and with a maximum afterburner, 15,600 lbs. The existing test stand is designed to accommodate a 40,000 lb thrust engine. Figure III D-12 shows constant sound pressure level contour plots at the center line of the jet engine in a plane parallel to the ground plane for the J79-1 and J79-5 jet engines.

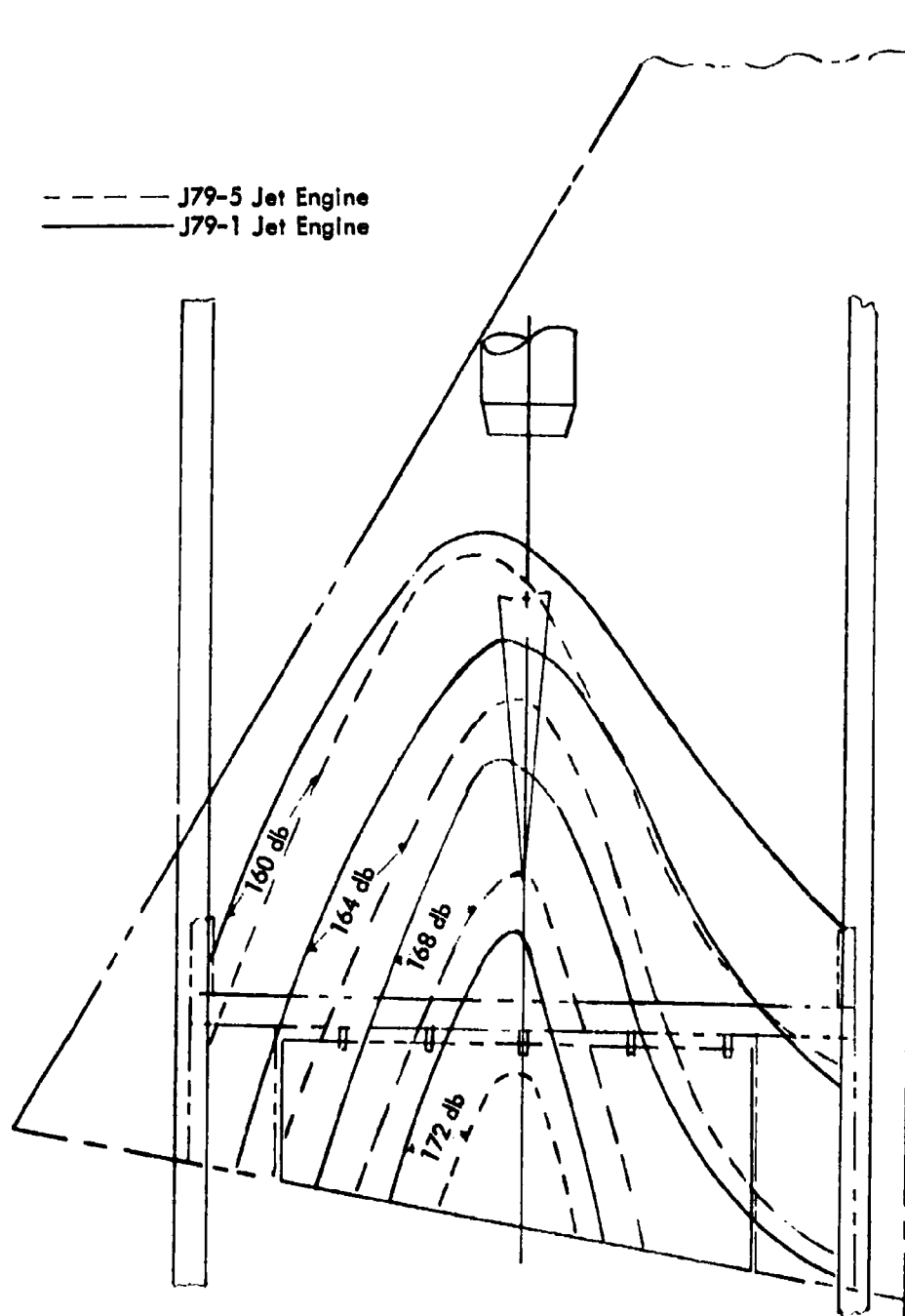
3. TEST METHODS AND SPECIMEN ARRANGEMENT

(a) Test Method

The first phase of the development and qualification testing of a structure is the siren test. These tests are qualitative in nature and designs are compared with one another to "build-in" sonic fatigue resistance. A single frequency (resonant) test level is determined from theory (See Section III D-5) and test data so that three hours of siren test level is equivalent to ten hours of ground afterburner jet noise environment. The resonant frequency is determined by varying the excitation frequency from 100 to 2000 cps while holding the pressure level constant. Specimen response is observed by monitoring the output of the strain gages during the test. Throughout the tests, frequency of excitation is adjusted to maintain maximum strain. Periodic inspections of the specimen are normally made every ten minutes and a marked change in a strain gage response signal is sufficient reason for stopping the test run for inspection.

After a test, each strain gage record is examined to check any other point of failure and to check specific time of failure. Strain gages are located at points of in-service failures or previous test failures, and they are located at points of maximum stress, determined by judgement in the case of simple structures, or by the use of stress coat in the case of complex structures.

The jet engine test stand is used to "semi-qualify" the structure which has proved satisfactory in the siren test. The test specimen is mounted in a manner



CONSTANT SOUND PRESSURE LEVEL CONTOURS
FOR TWO JET ENGINE SOUND SOURCES

FIGURE III D-12

dynamically similar to its vehicle installation and located in the engine test stand in an environment which is estimated to simulate its ground and take-off service environment (noise and temperature). It is exposed to this environment for 10 hours of afterburner time or whatever length of time the structure lasts. An inspection is made after 5 minutes of exposure, after 15 minutes of exposure, and thereafter at 30 minute intervals. In many cases, the specimens are monitored continually by the use of strain gages and microphones.

The final phase of the program is run using a full scale airplane ground afterburner test. Here a ten hour sonic fatigue test is conducted on a full scale B-58 airplane. The two in-board engines are operated simultaneously at maximum afterburner power in runs totalling ten hours. Frequent inspections establish the fatigue life of the various aircraft components.

(b) Specimen Arrangement

Most specimens tested have been full scale B-58 structural components. In some cases, simplified structures were used. Specimens are taken from stock production parts whenever feasible. Every effort is made to mount the specimens in such a manner as to simulate their operational mounting, and this usually involves attaching (bolting, riveting or welding) panels to a simulated airplane support structure and then to a rigid test fixture. Most of the siren testing has been done with a specimen mounted normal to the siren axis and with both sides exposed to the sound field. An investigation of the advantages of baffling the aft side of a specimen during normal incidence testing was made, and it was concluded that there was no advantage; baffling served only to reduce the specimen strain for each given operating condition. Investigations were also made to determine the effect of varying the angle of incidence of a specimen in the test chamber. This was done using a dummy test specimen. It was concluded that there was no particular trend in sound pressure level established as the specimen position was varied. Strain measurements on the specimen for a given sound pressure level was greatest with the specimen located 18" from the siren horn and normal to it. The strain level

measured with the specimen at 6" was less. It also reduced in steps as the specimen was rotated to 60°, 30°, and parallel to the siren axis. The conclusions drawn from this test were that there is probably an optimum distance at which a given specimen should be placed for testing and that the normal position is most efficient for translating sound energy into specimen responses.

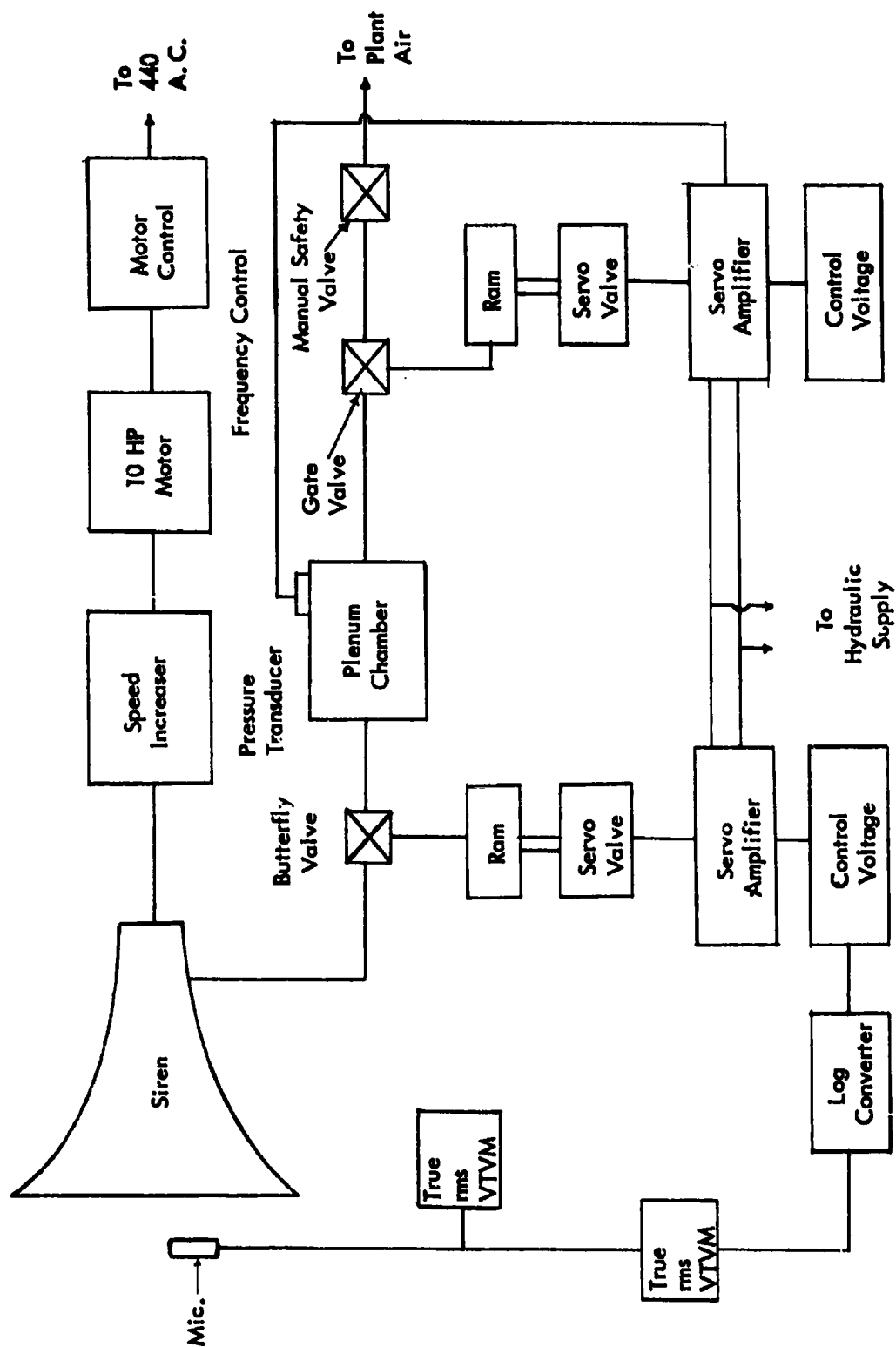
Specimens that are used in the jet engine facility are usually made from stock production parts except when "fixes for failure" are being tested and then the specimen may be specially made. Whenever possible, the specimen is located so as to duplicate its operational environment as closely as possible.

4. INSTRUMENTATION AND DATA ACQUISITION

(a) Siren Control

Figure III D-13 is a block diagram that shows the method used to control the sound pressure level and frequency of the siren. A 10 horsepower DC motor operating through a speed increaser with a gear ratio of 1 to 4,166 is used to drive the siren. Motor speed is controlled by varying the field voltage when operating below the base speed and by varying the armature voltage when operating above the base speed. This, in combination with the speed increaser, provides a siren speed range of 150 to 15,000 rpm corresponding to a siren frequency range of 20 to 2000 cps. The electronic controls regulate speed such that the siren frequency is held to within ± 0.4 cycles per second. The time required to cover the complete frequency range may be varied from 3 to 30 minutes (automatic rates of acceleration and deceleration are available).

A two channel electro-hydraulic servo system automatically controls the sound pressure level. Plant air flows through a 4" gate valve to a plenum chamber and then is passed into the siren through a 6" butterfly valve. Hydraulic rams operate both valves which are controlled by servo valves. A pressure transducer in the plenum chamber provides a signal to a servo control circuit which maintains a selected chamber pressure. Similarly, the output monitor microphone supplies a signal to the butterfly



SOUND PRESSURE LEVEL CONTROL

FIGURE III D-13

servo control circuit that allows the valve to maintain a selected sound pressure level in the sonic test chamber.

(b) Noise Measurement

In the siren facility, sound pressure level is measured with standard Altec BR200 microphone systems and monitored on Ballantine Model 320 true rms voltmeters. The data recording system for the jet engine facility is more complex and is shown in Figure III D-14. Such a system records 6 tracks of data simultaneously on one-half inch tape, handles the output from up to 10 groups of microphones, and has a frequency range of from 20 cps to 10,000 cps. The signal from the microphone is fed into the recording system, and attenuators preceding the 2 amplifiers are ganged together so that any incoming signal will not overdrive either amplifier. Attenuation is in 10 db steps. A microphone selector permits the selection of groups of 6 microphones, and a calibration signal is recorded between each group of microphones. Flush mounted sintered bronze faced and high temperature probe type microphones are used when required.

The data analysis system used for broad band jet engine noise (Figure III D-15) consists of an Ampex 306 tape recorder, an Ampex FL100 loop recorder, a Bruel and Kjaer Type 2109 spectrum analyzer, a General Radio type 1550A octave band analyzer, and a Bruel and Kjaer type 2304 level recorder. A panoramic sound analyzer is used to determine resonances and harmonics. Also some equipment is available for making statistical analyses of selected data.

(c) Response Measurement

Figure III D-16 is a block diagram of the response measurement system that emphasizes its two main divisions — data acquisition and data reduction. Many different types of strain gages have been tried, and experience has shown that epoxy backed foil type gages are satisfactory when small strain gages are needed, and Baldwin A-5-1 flat grid paper gages are satisfactory for applications involving medium to large size gages. Strain gages on the specimen are wired as single active arms in a bridge

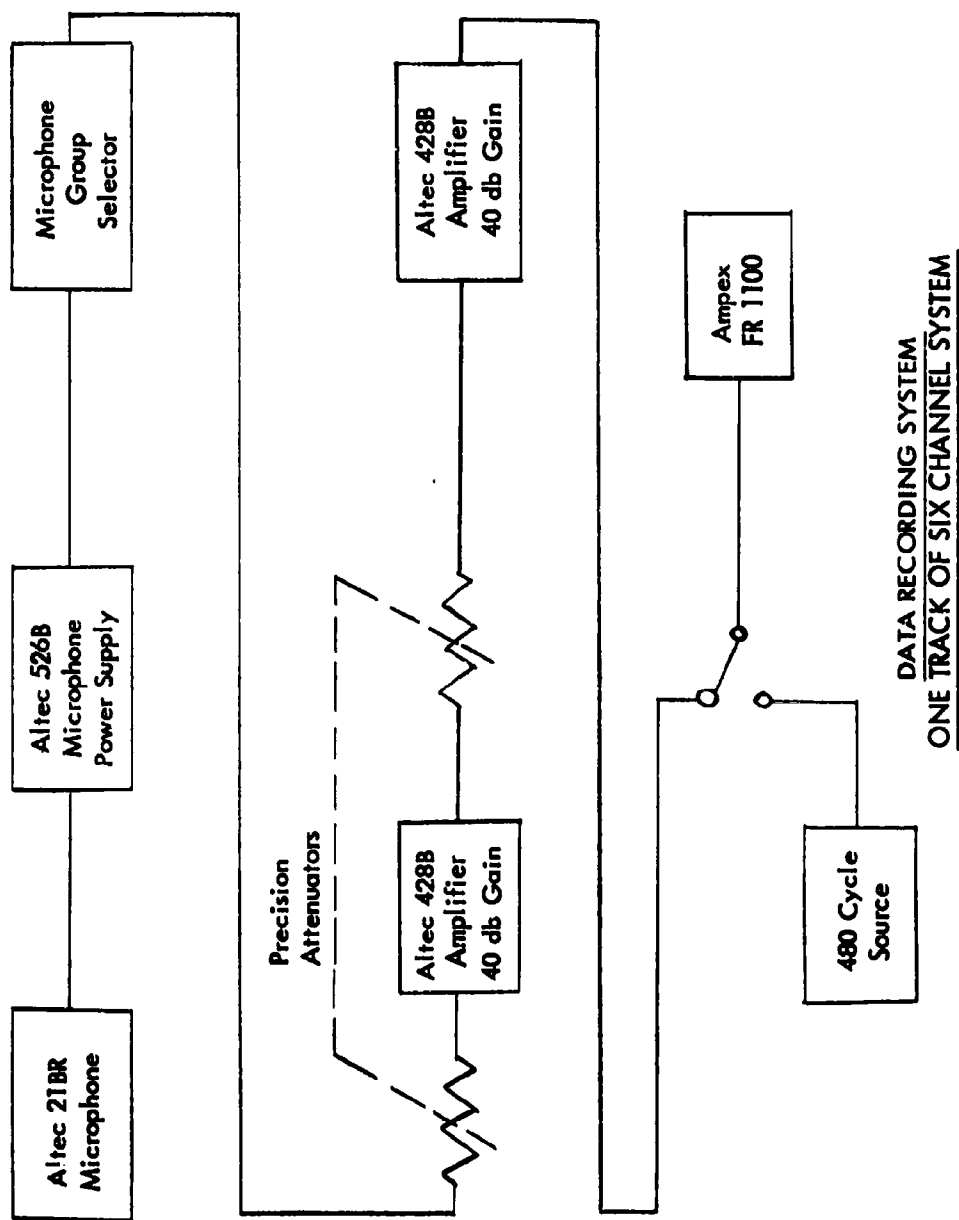
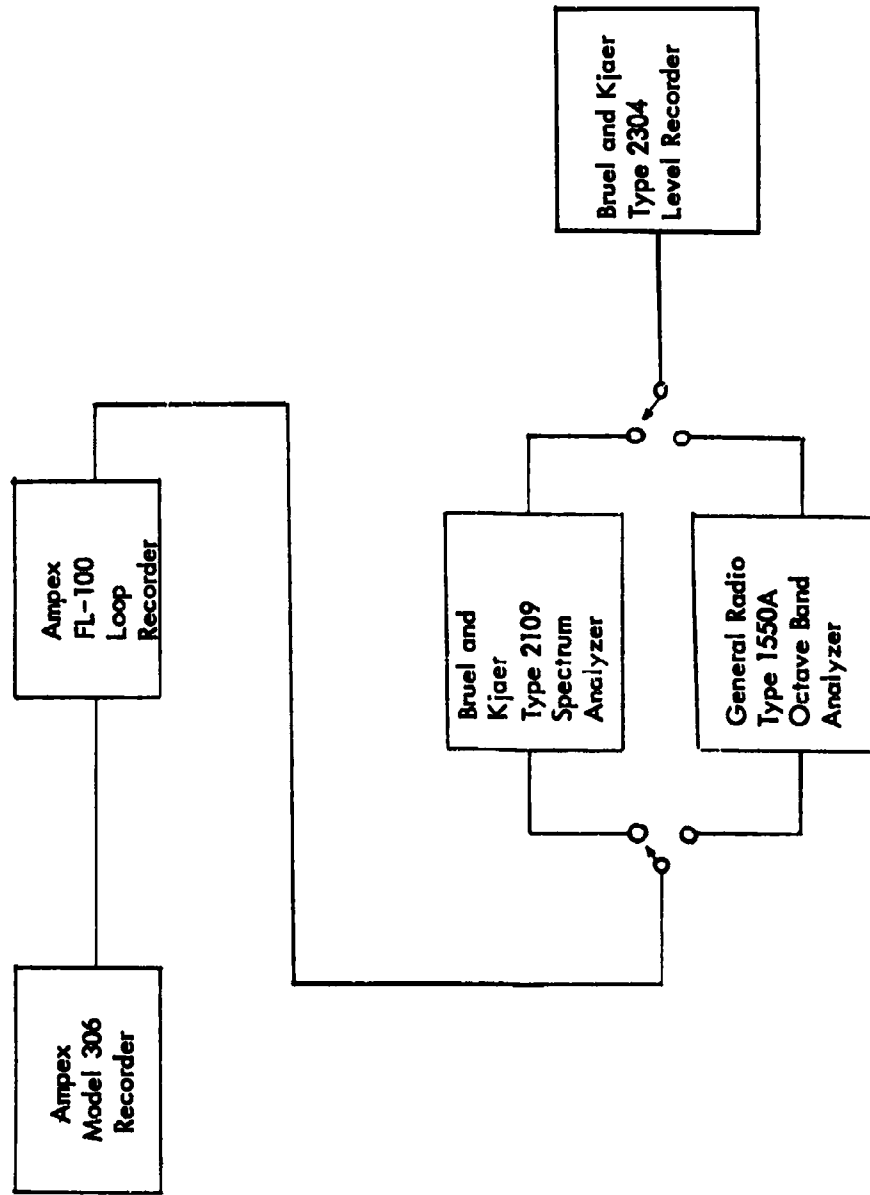


FIGURE III D-14



DATA ANALYSIS SYSTEM

FIGURE III D-15

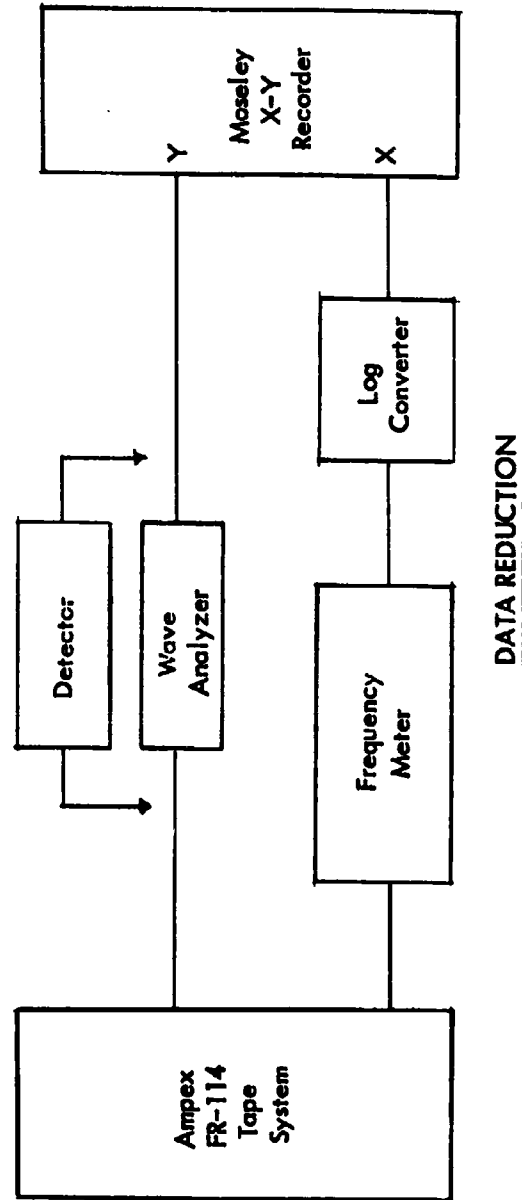
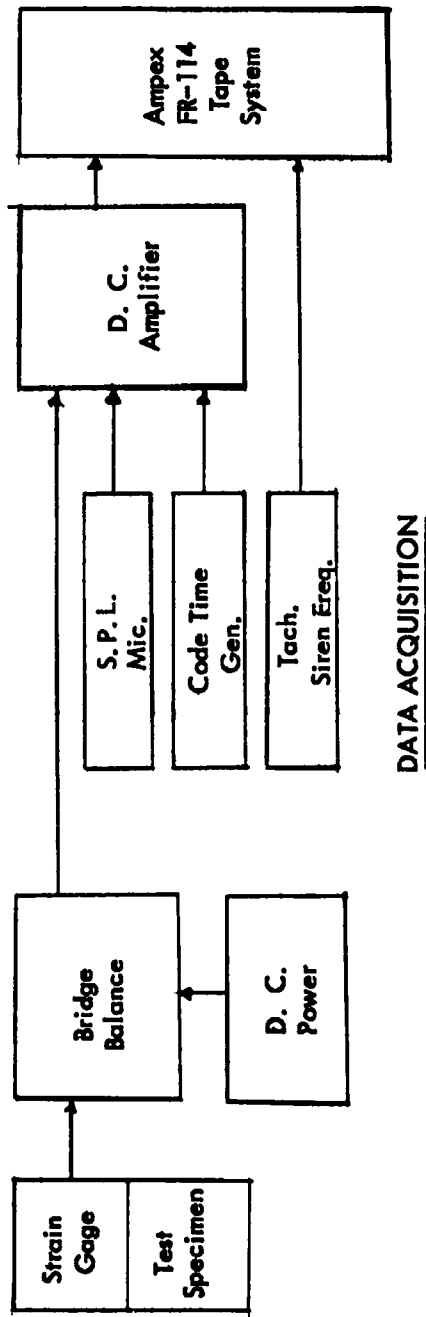


FIGURE III D-16

circuit which is excited by DC, and their outputs are amplified by chopper stabilized Kintel DC amplifiers before going to the recording system.

The signals from the strain gages (usually 3 or more) are recorded on magnetic tape with the signal from what is considered a critical gage being monitored visually on calibrated VU meters at the input of the record amplifier. Specimen failure is detected by wave shape variations (monitored with a Dumont dual beam oscilloscope - Model 322A) amplitude variations, and visual inspection.

The data is processed from tapes by use of a peak detector and a Sandborn direct writing recorder. Another system sometimes used for data processing is a Technical Products Company Model TP627 analyzer in conjunction with constant-pass-band filters of 6, 27, 100 or 200 cps. These systems allow the test data to be given in terms of peak value, average value, or power spectral density.

5. INTERPRETATION OF DATA

The purpose of the test program at Convair, Fort Worth, is research in material fatigue, proof testing, and the development of structure to resist sonic fatigue. Convair uses accelerated tests in the siren facility. The intensity of the sonic excitation in the test is such that three hours of siren excitation are presumed to be equivalent to 10 hours of service life when operating with the afterburners on the ground (See following discussion).

Data interpretation at Convair, Fort Worth is based on Miles' treatment of the response of a single-degree-of-freedom linear oscillator. Several minor modifications to Miles analysis are made, e. g. (a) modifications introduced by Regier and Hubbard to relate mean square stress to panel dimensions and (b) the incorporation of a multi-mode response factor as recommended by Powell and which is the ratio of the total mean square stress response of all significant modes to the mean square stress response for the test mode under consideration.

Random fatigue curves have been used, but no detailed information is available on the methods of constructing these curves.

The principal use of Miles' results appears to be in the selection of a

single-frequency test-level suitable for an accelerated (siren) test. The test-level is chosen so that a 3-hour siren life is equivalent to 10 hours of life at the noise level produced by ground operation with afterburner.

Using Miles' expression relating rms stress to the power spectral density of the excitation it is possible to select a siren sound pressure level which would produce the same rms stress. This is adjusted by two factors; the first of which is the multi-mode factor previously mentioned. The second factor is a 'peak stress factor' and is introduced as follows: from a frequency sweep of the test structure, the frequency of maximum response is determined and from this the number of cycles corresponding to 10 hours of life is found. From constant amplitude and random S-N curves two stress levels are found corresponding to this life, the ratio of these levels is the 'peak stress factor' and it is used to calculate an SPL that will produce a siren test life which is equal to the service life (N_L cycles to failure). This is the unaccelerated life which is then adjusted to give the desired 3-hour siren life (N_T cycles to failure). Using the constant amplitude S-N curve and the number of cycles corresponding to 3 hours a new stress level is found; the resulting stress increase can be converted to pressure level increase by reference to an experimentally determined relation between pressure and stress. An additional pressure increase is usually incorporated as a safety factor and is arrived at by doubling the number of cycles N_L to give N_M and finding the corresponding stress interval between the lives N_T and N_M . This stress interval is converted to a pressure change which is then added to the test pressure.

6. TIME AND COSTS

The costs of specimens vary with the intricacy of the specimen from \$50.00 to \$2000. The estimated total value of equipment, instruments, and building for the siren installation is \$200,000. The operating cost per hour is \$30.00 plus power requirements and overhead. For a given panel configuration, 1 to 3 specimens are used and 1 to 4 weeks time are required for the tests depending on the specimen complexity. Specimen

cost including jig construction, strain gaging, testing, data reduction, and report preparation is approximately \$1000 for the first specimen and \$500 for each additional specimen.

Convair's existing jet engine facility was built for uses in addition to sonic fatigue testing so that its cost would be misleading. A recent study, however, estimated that it would cost approximately \$200,000 to set up a test cell in another location specifically for sonic fatigue testing. This cost, while including all necessary services, did not include the jet engine. Such a facility would cost approximately \$500 per hour to operate.

7. COMBINED ENVIRONMENT TESTING

Although there are extensive environmental test facilities available, these are not set up for use with the sonic test program, and no combined tests are being performed in the siren facility. Testing that is done with the jet engine facility is considered to be a combined noise and temperature environment test.

8. BIBLIOGRAPHY OF RELATED REPORTS

Most of the reports generated are primarily for internal distribution and the following list is only to indicate the types of work carried on.

JET ENGINE TEST STAND

FZS-4-163, Structural Aspects of Magnesium Thorium Alloy in Design of B-58 Elevons, 26 March 1958, Revised 12 December 1958

FZM-4-1007, Report Covering Ten (10) Hour Sonic Fatigue Test of the One Cell Mag-Thorium Elevon On The Jet Engine Test Stand, 17 July 1959

Convair Flight Test Group reports have been written on each test request completed in the jet engine test stand facility. These reports have only internal distribution.

150 DECIBEL SIREN

FTDM1696, Test Number F6287, Control Surfaces - Simulated Mag-Thorium Elevons - Sonic Test of, 11 July 1957

170 DECIBEL SIREN

FGT 2128, Test Number F 7762, Wing Corrugated Spar - Sonic Fatigue Test, 22 January 1959

Test laboratory reports on all siren tests are being published. These have only internal distribution.

TEN HOUR GROUND SONIC FATIGUE TEST OF A B-58 AIRPLANE

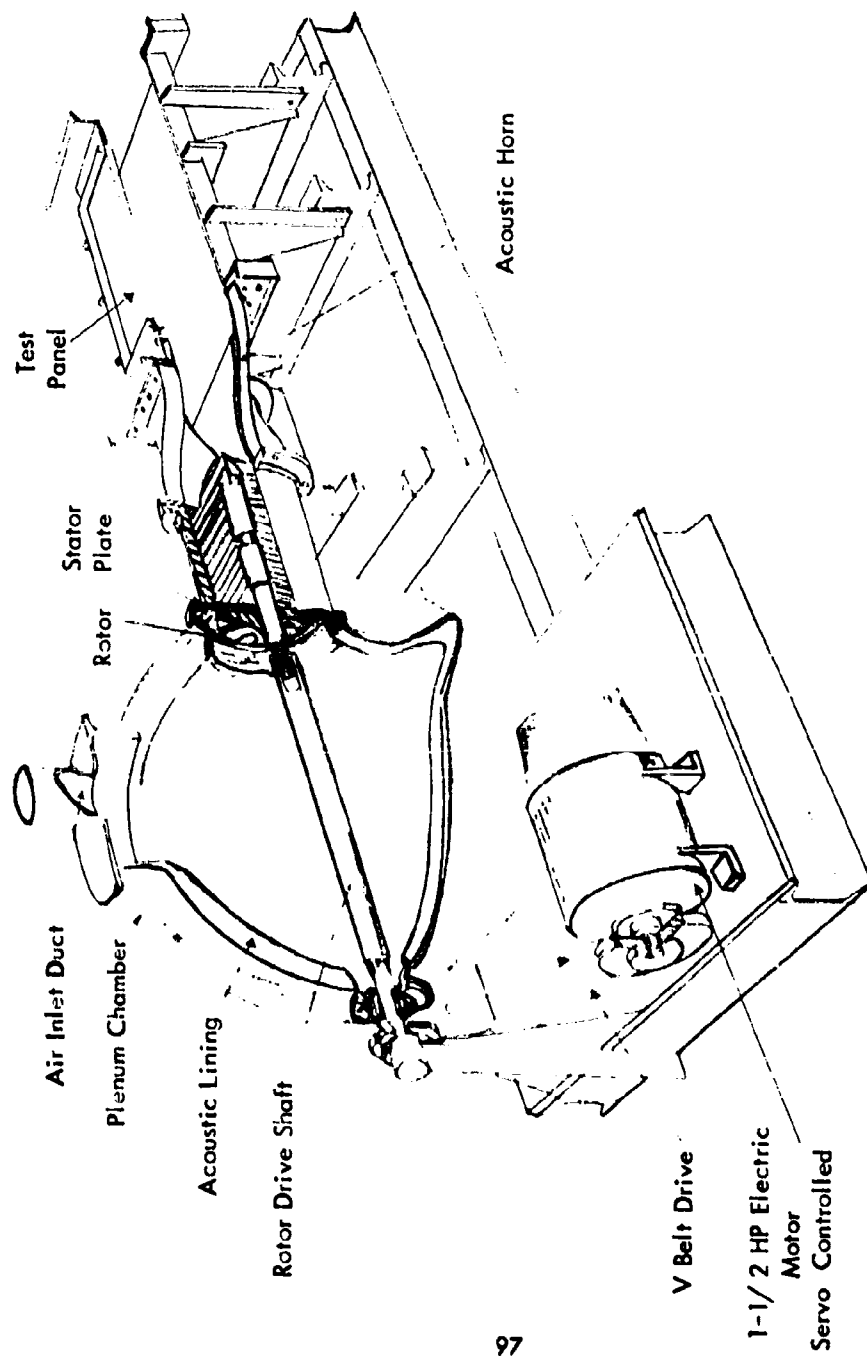
FZS-4-212, Ten Hour Maximum Afterburner Power Ground Sonic Fatigue Test Of B-58A 5/ N 58-1021, 16 May 1960

1. GENERAL DESCRIPTION

General Dynamics/Convair has in operation a discrete frequency siren facility. Figure III E-1 is a schematic drawing of the facility that illustrates its principal components. These are a Ford Industrial Engine which drives an Allison supercharger compressor that, in turn, supplies air to the siren chopper through a spherical plenum chamber. A progressive wave test section is used to test various types of panels. The 110 HP drive and compressor supply 35 air HP to the plenum chamber at a maximum flow of 1400 cfm, and the exhaust air from the test chamber passes out through an acoustically lined exit duct.

2. TYPES OF SOUND SOURCES

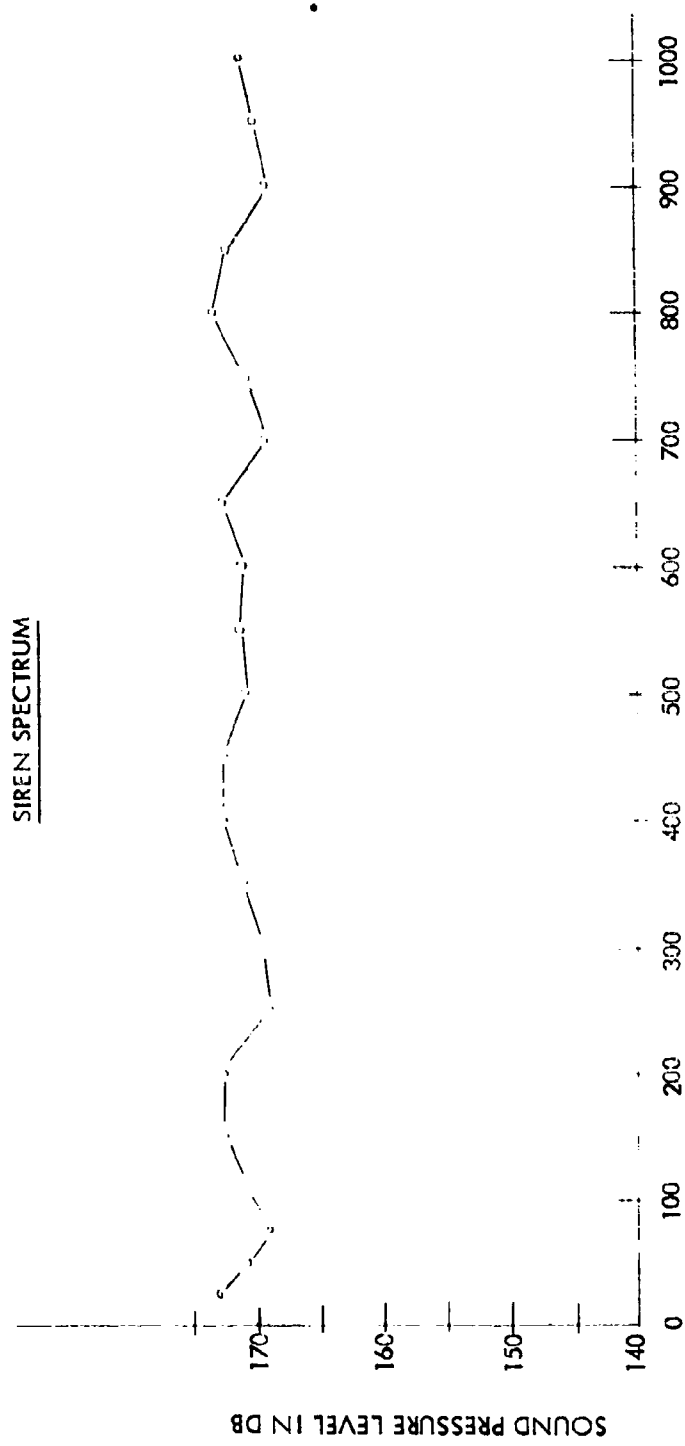
A discrete frequency siren with a range of 25 to 1100 cps is used as a sound source. It was designed in consultation with Drs. Leonard and Rudnick of UCLA and is, in many ways, similar to the siren at Douglas, Santa Monica and North American, Columbus. Figure III E-2 is a plot showing the sound pressure level of the siren at various points over the frequency range. Table III E-1 tabulates the percent harmonic content for 4 frequencies at 3 positions in the test chamber. Additional measurements show that there is very little variation in the harmonic content with position along the test section. The maximum output of the siren at the specimen location is in excess of 170 db. Some investigations have been made of the variation in pressure over the area used for testing specimens by placing a microphone on a trolley that travels diagonally over the test area. The results of these measurements were not available for this report.



97

HIGH INTENSITY SIREN FACILITY

FIGURE III E-1



SIREN SPECTRUM

FIGURE III E-2

Overall S. P. L. = 165 db

MICROPHONE POSITION IN SIREN CHAMBER	HARMONIC CONTENT (%)						
	Fund. Freq.	1st	2nd	3rd	4th	5th	6th
12 INCHES FROM UPSTREAM END OF CHAMBER	100 cps	100	27	11	10	10	--
	200 "	"	11	7	1	1.6	--
	300 "	"	12	6	7	7	1
	400 "	"	13	6	10	12	6
24 INCHES FROM UPSTREAM END OF CHAMBER (MIDPOINT OF CHAMBER)	100 cps	100	21	8.5	4	2	--
	200 "	"	16	6	11	4	--
	300 "	"	8	3	4	6	4
	400 "	"	42	10	4	3	7
28 INCHES FROM UPSTREAM END OF CHAMBER	100 cps	100	28	10	4	5	3
	200 "	"	14	4	12	5	--
	300 "	"	12	6	2	4	1
	400 "	"	65	15	7	8	4

HARMONIC CONTENT IN SIREN CHAMBER

TABLE III E-1

Convair also has a small cold flow random noise generator that produces between 145 and 152 db (octave band levels) in a semi-anechoic chamber. This facility is primarily used for electronic component testing.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

The frequency of structural resonance of a test panel which results in the greatest indicated strains is found by conducting a frequency response survey. The siren is operated at this frequency until a fatigue failure appears or until a pre-determined number of hours have passed, whichever occurs first. The SPL maintained during the test is calculated to give damage over the stipulated period equivalent to or greater than that which would occur throughout the life of the aircraft (see Section III E 5). When conducting the preliminary frequency survey of a panel to determine the mode in which it will be fatigue tested, the applied acoustic pressure is maintained at a constant level (as the frequency is varied) that corresponds to the spectral level experienced in service and then during the test that pressure is increased to the "equivalent" level. During this period, a plot of all strain gage responses is made. If the pressure strain curves are linear, the calculated equivalent test pressure is used for the fatigue test. If any of the plots show non-linearity characteristics, then the pressure is reduced until linearity is re-established. The fatigue test is then run at this lesser pressure and the fatigue life at the required SPL is determined from an S-N curve that has been prepared. Section III E 5 discusses the method in more detail.

The specimens tested are up to 22" wide and 44" long and they are mounted with clamped edges. Micarta in the clamping arrangement is used to reduce stress concentrations at the edges of the panels. All specimens have been tested in the progressive wave chamber by sound at grazing incidence. On some of the tests performed 4 or more microphones were used to monitor the sound pressure level acting on the specimen. Strain gages are located at those points on the specimen where it is judged the largest stresses will occur. On complex panels many strain gages may be used, although 4 gages are used as a minimum,

and failure is detected by observing a change in resonant frequency or strain amplitude. In addition, visual inspections are made at least every half hour during the test period. When an area is found to be critical in a vehicle, and a panel is to experience a very severe noise environment, 2 or 3 identical panels are tested.

4. INSTRUMENTATION AND DATA ACQUISITION

Figure III E-3 is a block diagram of the basic instrumentation systems that have been used for testing panels. At the present time, the instrumentation system is being modified and equipment for automatic control and analysis is being added. Details are not available on these modifications.

5. INTERPRETATION OF DATA

The main purpose of the test program at Convair is to proof-test new designs. The evaluation procedure that is used may be separated into the following broad phases:

1. A statistical analysis is made of the jet acoustic pressure data at the station of interest.
2. The least damped maximum strain resonant mode and corresponding frequency of the test panel is determined.
3. A test acoustic pressure based on relative slopes of applicable probability curves of jet pressure and stress cycle curve for a structural configuration of a test panel is determined.
4. The panel is tested to failure (or a stipulated time) at the selected acoustic pressure and frequency. (Note: A test time of 15 hours at 165 db is stipulated for 380 wing structure near the engine exhaust.)
5. The failure is interpreted in terms of random acoustic excitation provided by the jet.

The techniques used are based on experimental determinations of the probability distribution of peak pressure in a jet-engine field and on typical (constant-amplitude) S-N data.

One application of this information is in the establishment of a discrete

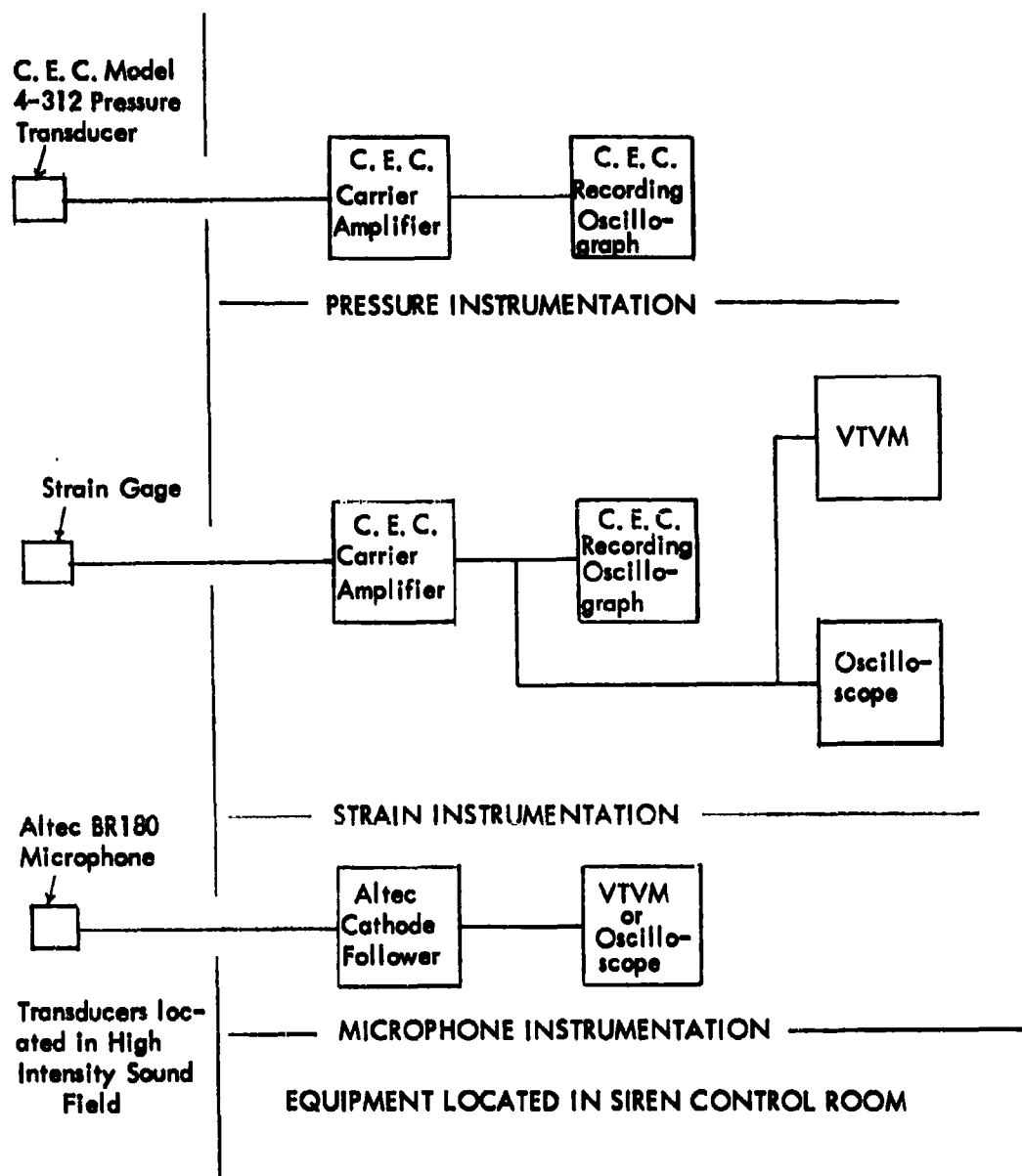


DIAGRAM OF BASIC INSTRUMENTATION

FIGURE III E-3

frequency test in lieu of random testing; this is accomplished as follows:

By scanning a tape-recording of near-field pressures around a jet engine, measurements are made of the percentage of time during which various pressure levels are exceeded; this information is presented in terms of a graph relating the ratio peak/rms pressure to the probability of exceeding this pressure ratio. This curve is then replotted in terms of peak pressure versus the number of hours in the desired life of a structure during which a peak pressure is exceeded. The conversion is carried out by re-scaling the probability axis in terms of hours to failure by allowing 100% of the time to equal the desired life (e.g. 10,000 hours) and by re-scaling the pressure ratio axis to refer to some rms pressure (e.g. 148 db).

The orthodox, constant-amplitude S-N property of the structure is now taken as a straight line which is tangent to the previously constructed curve, and the point of tangency is used to define a critical pressure. This critical pressure is taken as that "which will most likely cause a structural failure". The area under the probability curve is now divided by the critical pressure yielding a value of 'hours to failure' and the critical pressure point is translated to this new abscissa. Through the point thus obtained a new line is drawn parallel to the original "normalized S-N curve". A structural failure at any point on this curve under sinusoidal excitation is considered equivalent to a failure at the number of hours chosen for the life (e.g. 10,000 hours) under random excitation at the chosen rms level (e.g. 148 db).

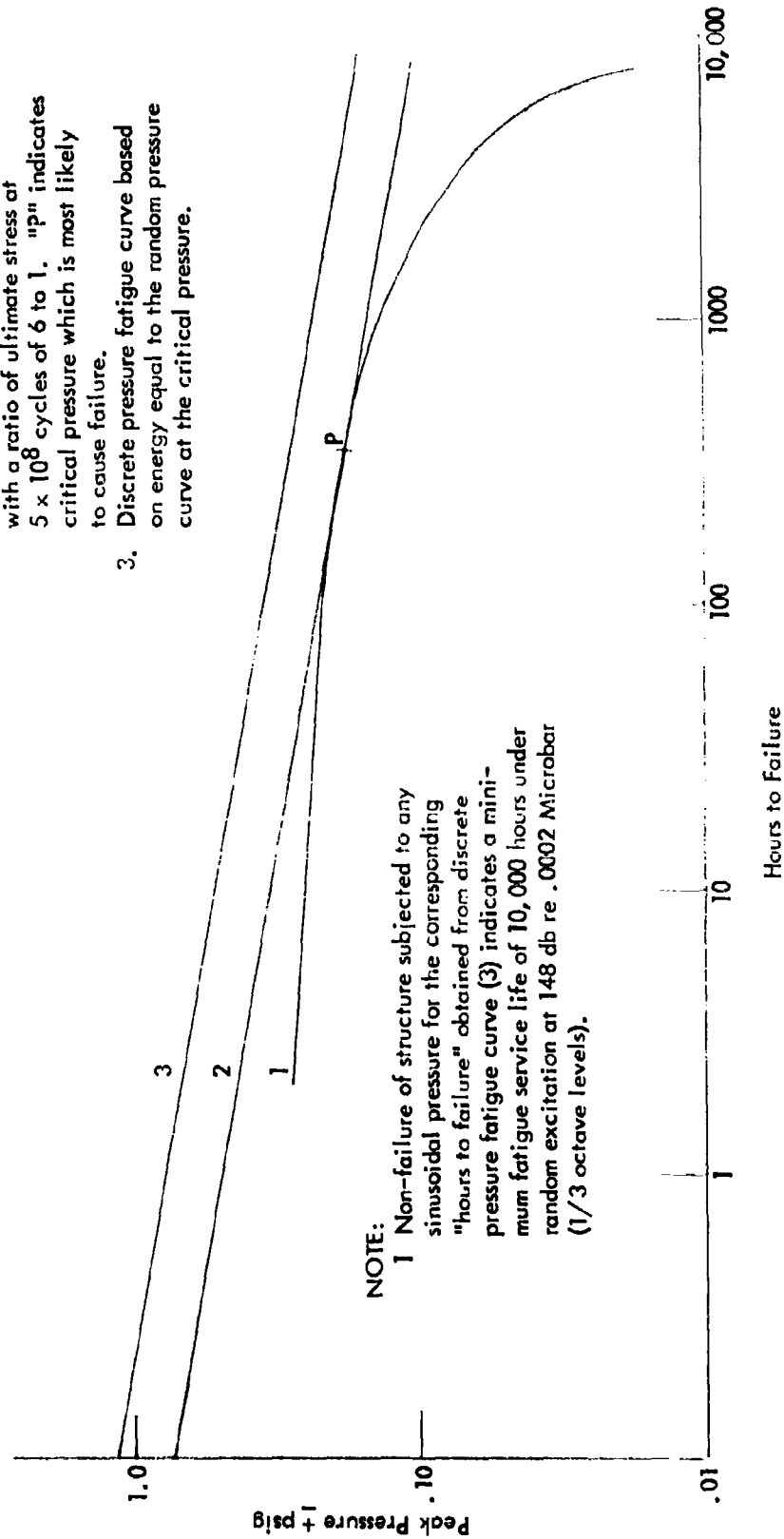
The construction of these curves is illustrated in Figure III E-4 which is taken from Convair Memorandum Report DG-G-183.

The following type of information is presented by Convair to summarize siren test results.

1. Frequency surveys of the strain gages, strain versus frequency
2. A description of the panel and its mounting configuration showing strain gage locations.
3. A strain versus sound pressure plot of the various strain gages.

LEGEND:

1. Cumulation of peak pressure hours in 10,000 hours for C-J-805 engine.
2. Fatigue curve based on an S-N curve with a ratio of ultimate stress at 5×10^8 cycles of 6 to 1. "p" indicates critical pressure which is most likely to cause failure.
3. Discrete pressure fatigue curve based on energy equal to the random pressure curve at the critical pressure.



ENVIRONMENTAL ACOUSTIC PRESSURE VS. HOURS TO FAILURE

FIGURE III E-4

4. The level at which the test is conducted.

5. The number of hours to failure and the frequency at which the test was made.

At the present time, the data are reduced manually.

6. TIME AND COSTS

The approximate cost of the facility is \$42,000. This estimate is broken down as follows:

Physical set-up	\$10,000.
Instruments and Control	12,000.
Siren set-up	20,000.

It is estimated that 50 man hours of effort are required to perform a test on a simple flat panel. This includes shop set-up time and data reduction.

7. COMBINED ENVIRONMENT TESTING

Combined sonic fatigue and temperature tests have been performed up to 600°F. and down to -67°F. This has been done by introducing cooling or heating in an enclosed space on the back side of the panel. For cold tests CO₂ is sometimes introduced into the air stream on the sound side of the panel.

8. BIBLIOGRAPHY OF RELATED REPORTS

The following references are concerned with Convair's method for determining fatigue life of a given structure.

GETLINE, GORDON L., "Correlation of Structural Fatigue Relative to Discrete Frequency - Constant Amplitude and Random Acoustic Excitation", DG-G170.

Author's Abstract

This paper describes the characteristics of noise generated near the exhaust nozzle of a turbojet engine with a highly choked nozzle. These characteristics are described in terms of peak pressure amplitudes and their probability rate of occurrence. Procedures employed to interpret those data in terms of equivalent application of discrete frequency-constant amplitude pressures are discussed. Based on this equivalence, a method is proposed whereby the fatigue life of an aircraft structural element which is exposed to random acoustic excitation in service may be predicted on the basis of fatigue test data obtained under discrete excitation.

KAMPS, E. C., "Statistical Evaluation of Near Field Sound Pressure Generated by the Exhaust of a CJ 805 (J79) Turbojet Engine", DG-G176, November 1957.

Summary

The procedure for making a statistical evaluation of near field sound pressures is presented. The results of the work are given in the form of acoustic peak pressure probability curves and a comparison of the measured data from the CJ 805 engine to a Rayleigh distribution. The paper shows the Rayleigh distribution to be more conservative than the actual distribution.

KAMPS, E. C., "Application of Statistical Near Field Sound Pressure Data (CJ 805 Engine) for Prediction of Fatigue Life of Structural Panels", DG-G183, August 1957

Summary

The paper discusses a study that investigated pressure peaks from an actual engine. This involved determining absolute magnitude and rate of occurrence with respect to operation of the engine. The application of the data obtained for the prediction of fatigue life of structural panels is presented.

III-F. DOUGLAS AIRCRAFT COMPANY SANTA MONICA, CALIFORNIA

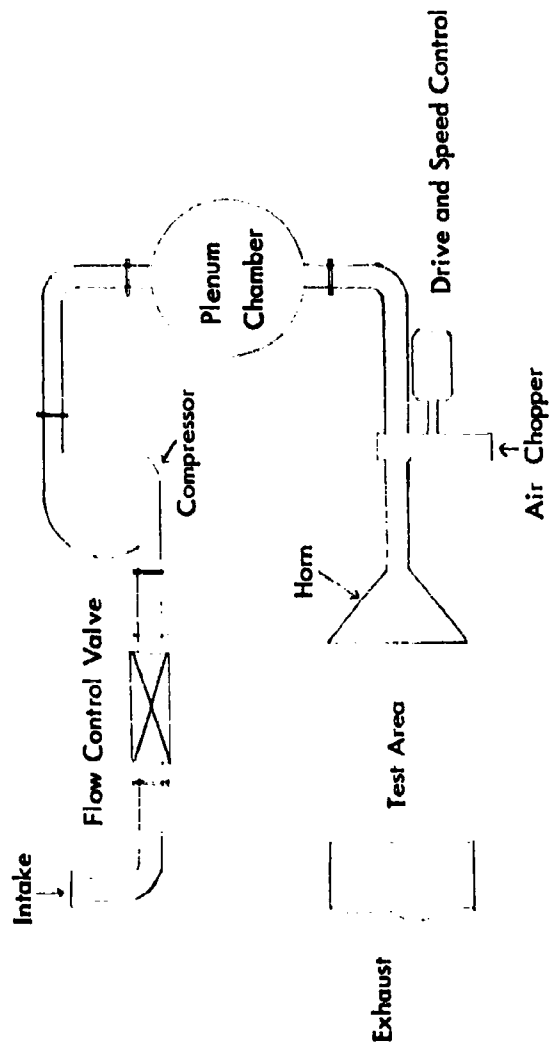
1. GENERAL DESCRIPTION

The primary programs that have required SF analysis and testing are the RB/B-66 Aircraft and the DC-8 Transport. In the development of structure to withstand the noise environment of these vehicles, Douglas used a discrete frequency siren facility located at Santa Monica, and the formalized proof test of a given structure was performed in a jet engine facility located at Edwards Air Force Base, California.

Figure III F-1 is a system diagram of the siren facility. Figure III F-2 is a plan view of the siren facility installed in a pit below the laboratory reverberation room. Two centrifugal pumps deliver air at rates up to 4080 cfm at 5 psig. The compressor surge is attenuated by the plenum chamber which is a tank of 11 cu. ft. free capacity partially filled with glass fiber to reduce chamber resonance. The 10 ports of the siren deliver oscillating pressures through 10 tapered tubes to the horn. The test chamber is 5 ft. long, 4 ft. high, and 1 foot deep. It is terminated in a 60 foot duct (including 4 right angle bends) lined with a sound absorbing material. The concrete walls of the duct diverge for the first 6 feet where it connects to the chamber to allow the depth of the sound absorbing lining to be gradually increased to its full thickness of 6 inches. This is to eliminate or reduce an impedance mismatch to prevent sound reflection. The final section of the duct rises vertically and exhausts 35 ft. above ground level. The intake duct is also vertical and stands next to the exhaust.

The sound pressure is controlled by varying the air flow to the first compressor. A 15 in. electrically controlled Iris valve is used here. A selsyn indicating system is linked to the control room. The fundamental frequency is controlled by the rotor drive motor, whose shaft passes through the plenum chamber. A Ward-Leonard control system provides the speed control from 300 to 6000 rpm.

SIREN SYSTEM

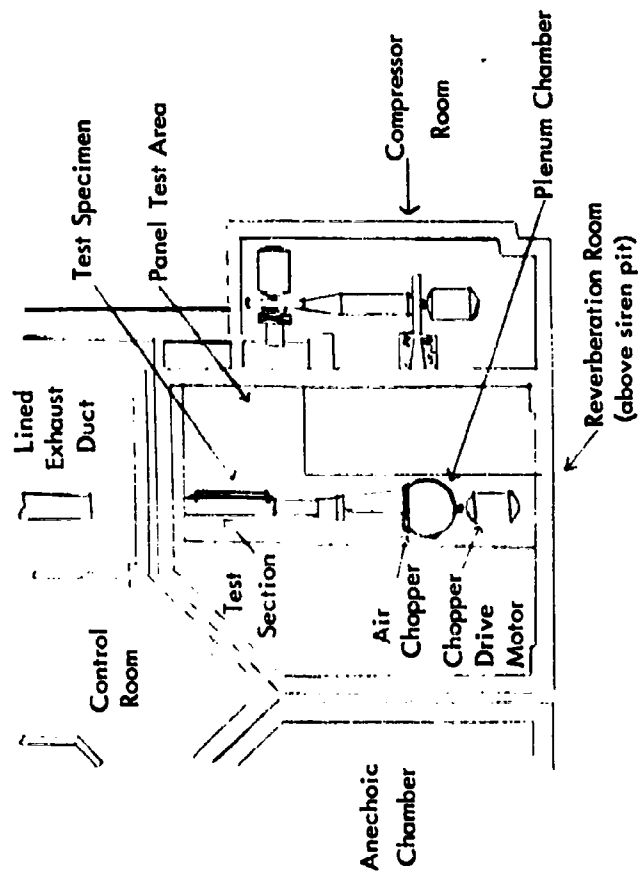


SIREN SYSTEM

FIGURE III F-1

DOUGLAS, SANTA MONICA

SIREN INSTALLATION



SIREN INSTALLATION

FIGURE III F-2

2. TYPES OF SOUND SOURCES

The types of sound sources used at Douglas include a discrete frequency siren and a jet engine test stand.

(a) Jet Engine

The jet engine facility which is located at Edwards Air Force Base in California is set up for the purpose of proof testing a structure. The actual development of the structure is accomplished using the siren sound source.

(b) Discrete Siren

Drs. Isadore Rudnick and Robert Leonard of UCLA were consultants on the design of the siren. The frequency range is from 50 to 1000 cps.

Figure III F-3 shows discrete point measurements of sound pressure level versus frequency. Figures III F-4, III F-5, and III F-6 are three graphs of spatial distribution of sound pressure level with distance with a typical test panel in place. These graphs illustrate the sound pressure level gradient at the center plane of the siren test chamber for different vertical, horizontal (normal to airstream), and horizontal (parallel to airstream) distances from the center of a typical test panel. The SPL data shown on these graphs were obtained with a constant blower setting during the siren operation.

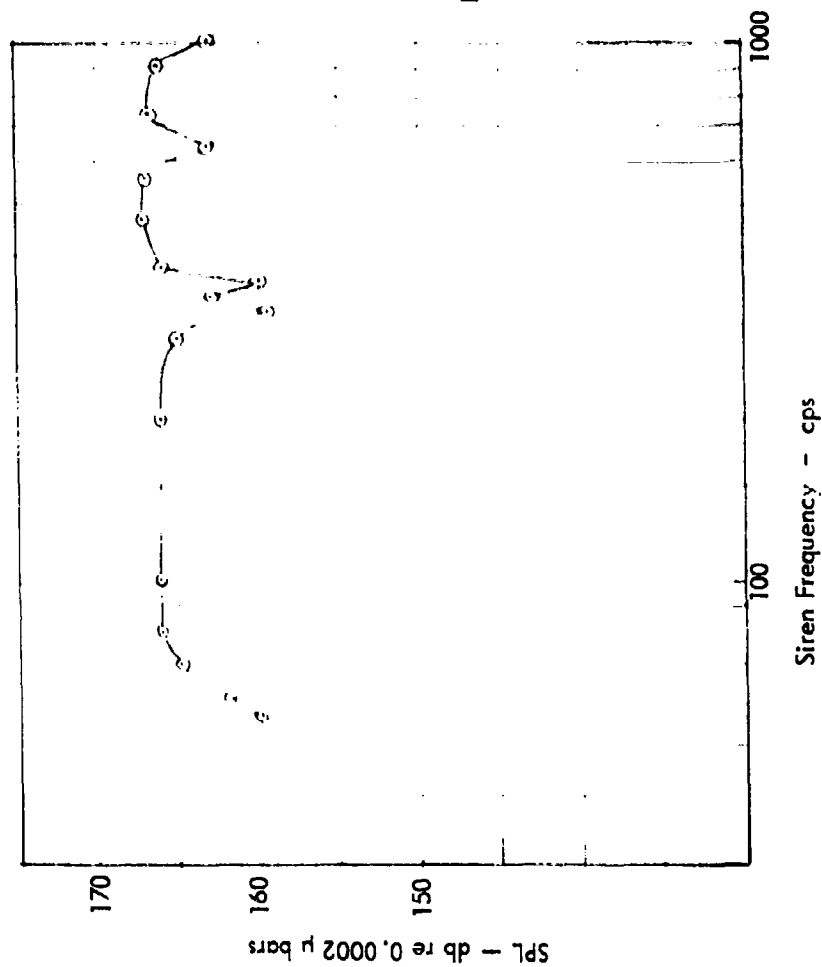
The blade port interaction of the siren was designed to produce an approximate sine wave near 50 cps. At frequencies approaching 150 cps and above, the pressure wave at the test section is approximately a saw tooth at maximum sound pressures. The high frequency output is ultimately limited by horn losses at frequencies approaching 1000 cps.

The port maximum width is two inches; its periphery is approximately 13 inches. The rotor has 10 blades 4-1/2 inches wide at the tip and is 25 inches in diameter.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

The following brief description of the methods used for testing structure

DOUGLAS, SANTA MONICA

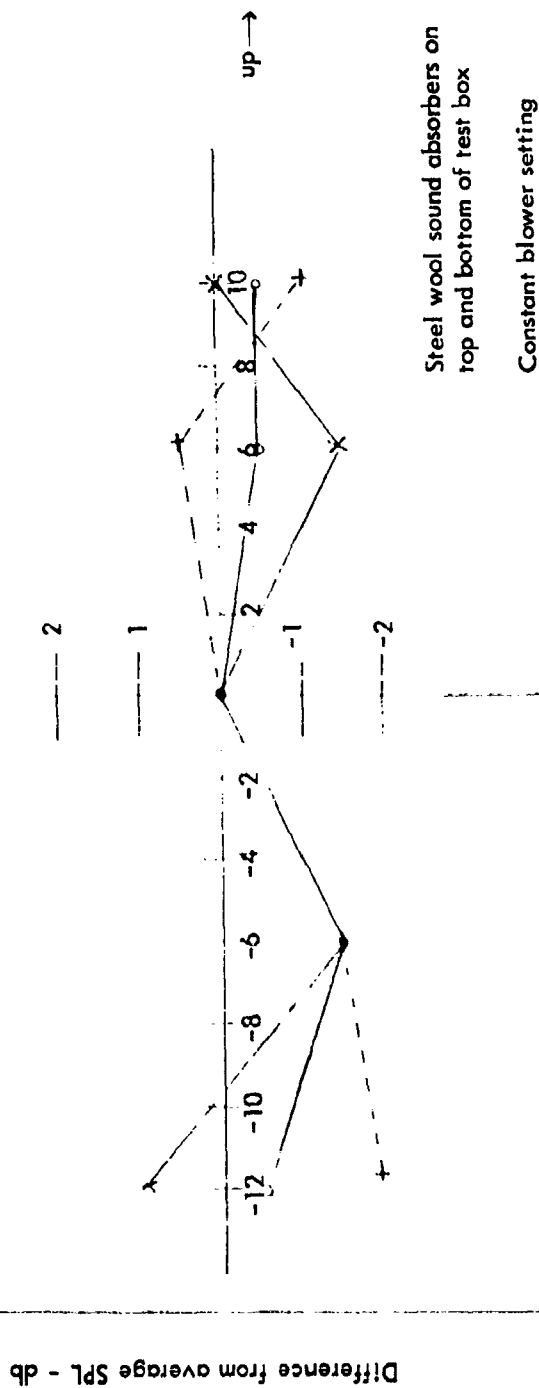


NOTE: This is a generalized curve. Max. SPL will vary with panel shape and panel response.

MAXIMUM SPL VS. FREQUENCY

FIGURE III F-3

- x 0-500 cps average
- + 500-1000 cps average
- o all freq. average



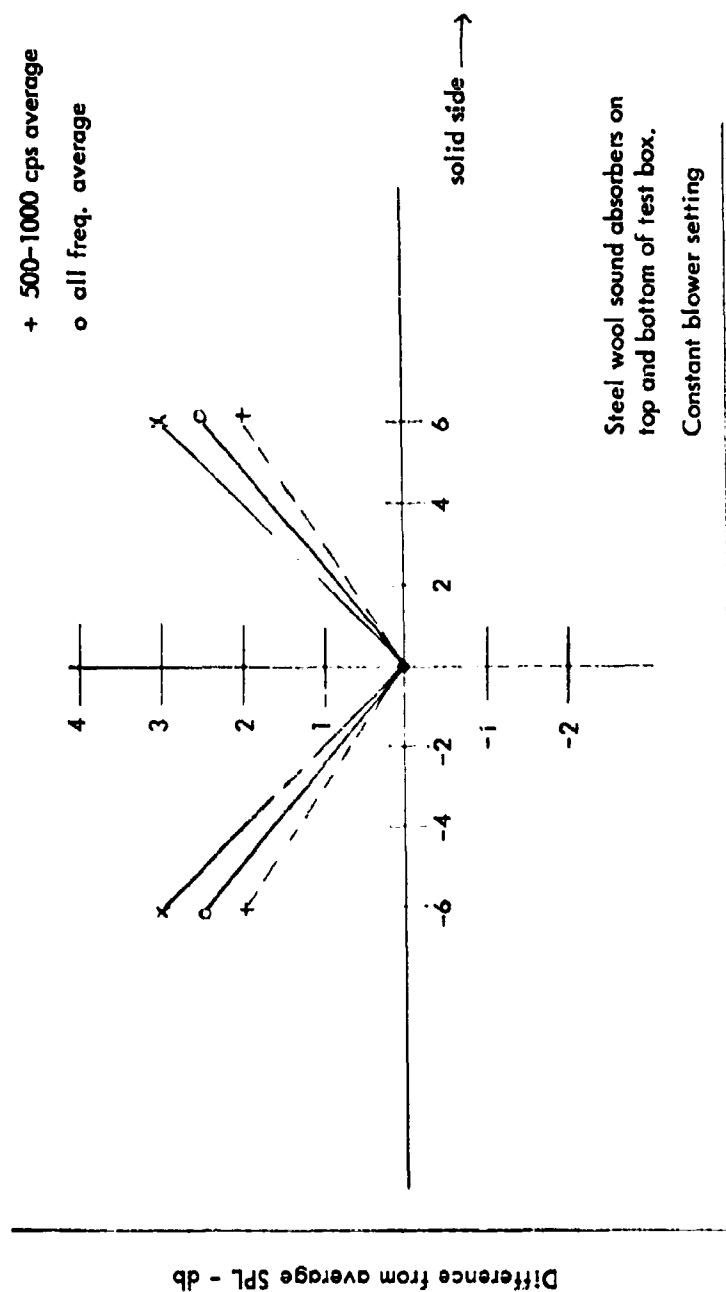
Distance from panel center - inches

ACOUSTIC GRADIENTS IN CENTER PLANE OF SIREN TEST CHAMBER (VERTICAL)

FIGURE 111 F-4

DOUGLAS, SANTA MONICA

- x 0-500 cps average
- + 500-1000 cps average
- o all freq. average

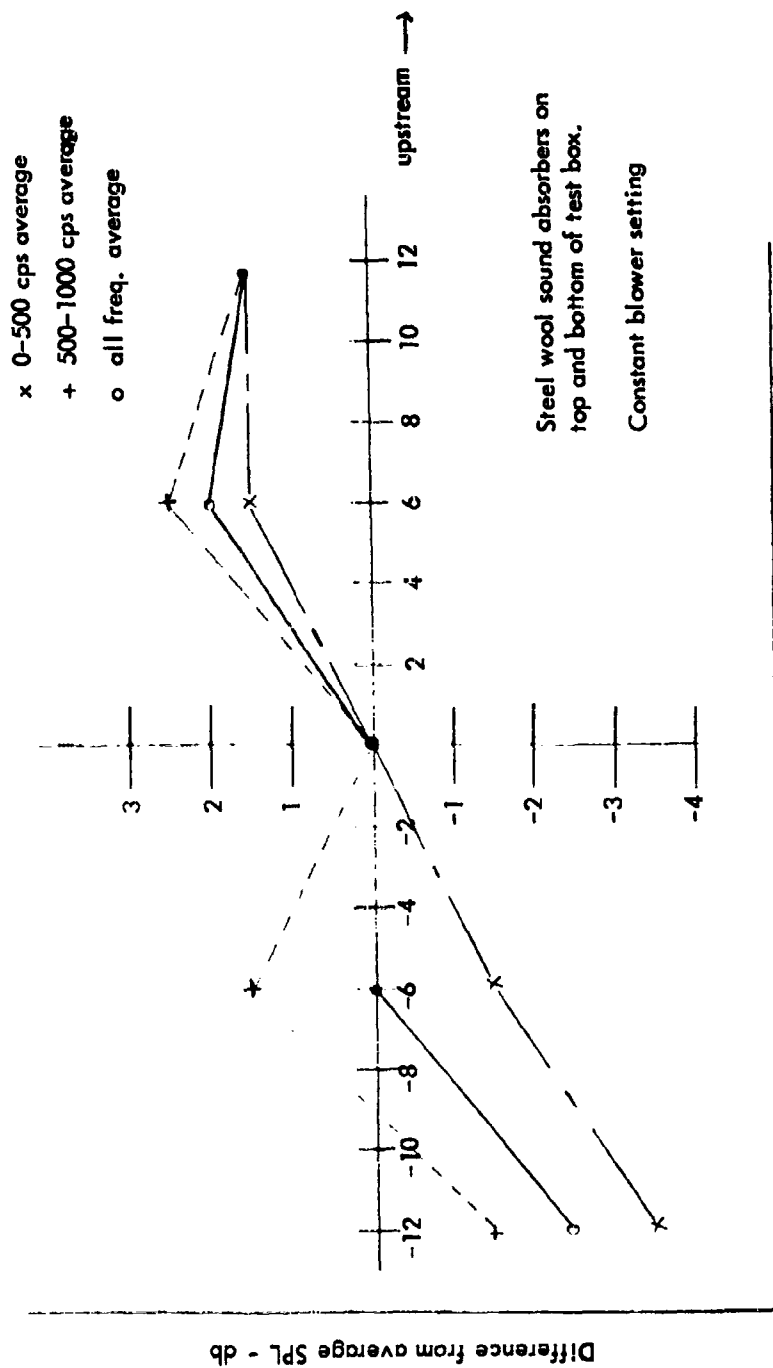


Distance from panel center — inches

ACOUSTIC GRADIENTS IN CENTER PLANE OF SIREN TEST CHAMBER (HORIZONTAL - NORMAL TO AIR STREAM)

FIGURE III F-5

DOUGLAS, SANTA MONICA



Distance from panel center — inches

ACOUSTIC GRADIENTS IN CENTER PLANE OF SIREN TEST CHAMBER (HORIZONTAL - PARALLEL TO AIR STREAM)

FIGURE III F-6

from the DC-8 aircraft is typical of the test methods used at Douglas. Only a description of the physical procedure is given here since the theory and methods of calculation are given in Part 6.

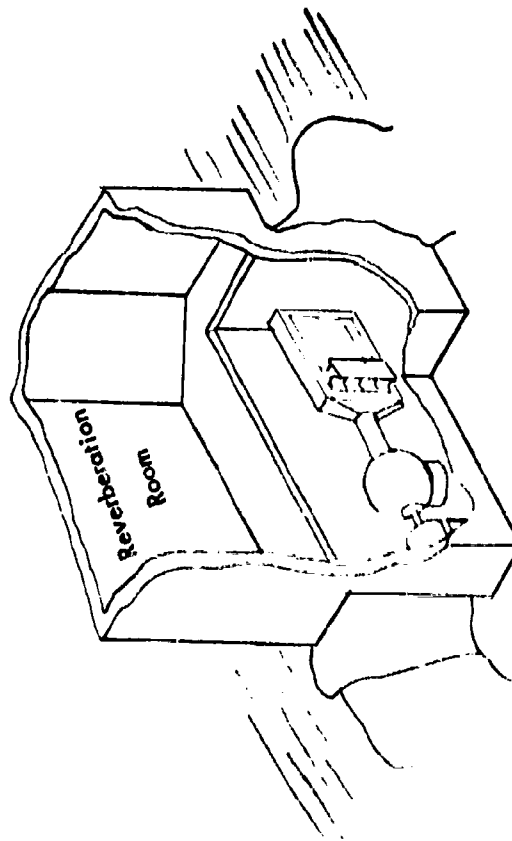
To determine the resonant frequency of major modes the rms voltage outputs of the strain gages on the specimen are obtained as the specimen is excited at a constant pressure level over a frequency range of 50 to 1000 cps. The frequency response curve at this sound pressure level is plotted. In the case of non-linear panels, the frequency is adjusted so as to obtain the maximum rms gage output at each major resonance. Since the natural frequency of a panel acting non-linearly is a function of the amplitude of deflection, the siren exciting frequency must be adjusted to the frequency corresponding to the level of excitation. The strain gage outputs are converted to rms stress and plotted against sound pressure, and this data is used to calculate a correction factor for the effect of non-linearity.

The same excitation pressure is applied to the specimen at each of the major resonances for an equal length of time. If failure does not occur, then the excitation level is increased by 3 db and the procedure is repeated until failure occurs or the panel lasts some calculated number of hours at a given sound level. This test method is discussed and examples are presented in the report listed in Section 8, "Load Computations used in Acoustic Fatigue Tests of DC-8 Structure", and, as has been mentioned, the theory is discussed in Section 6.

Figure III F-7 is a cut-away view of the siren test pit. It has approximately 100 cubic feet of excess space available at the test section which can accommodate specimens up to 20 square feet in area. However, most panel specimens are generally 4 square feet in area. Some types of structures that have been tested in the Douglas facility include conventional stringers, bonded beaded inner skin, and honeycomb panels. In preparing a specimen, a large enough section of the actual structure is usually used so that the test panel boundary conditions are approximately the same as those on the aircraft (panel of interest may represent only 20% of the specimen). The specimens are tested at grazing incidence in the progressive wave test section with

DOUGLAS, SANTA MONICA

SIREN TEST PIT
Showing Wing Trailing Edge Structure
In Test Position



SIREN TEST PIT

FIGURE III F-7

one side of the panel exposed to the sound field. Spatial distribution measurements are made over the specimen area when the specimen is considered to be "flimsy" since its response can influence the pressure distribution.

Failure of a specimen is detected by response change and regular inspections. At the beginning of a test, the inspection interval is quite short (5 minutes) but as the test progresses, the intervals increase to 10 or 15 minutes. Prior to any testing, they have a standard pre-test inspection which is the same as that used on an actual airplane.

4. INSTRUMENTATION AND DATA ACQUISITION

The following description of the measurement system used at Douglas in conjunction with the siren facility is compiled from an investigation of the various reports and papers published by Douglas. The control room adjacent to the siren facilities and the general acoustics laboratory have a wide data acquisition and reduction capability that can be used in the facility. Standard equipment, however, include the following:

(a) Noise Measurement

Microphones

Western Electric 640AA
Altec 21, BR 200

Ampex tape recorder, Model S3509 (three parts)

Tape transport
Model 350 amplifier system (AM)
Model 306 amplifier system (FM)

Sound-spectrum analyzers

Western Electro Lab sound-spectrum analyzer,
Type 1000B
Condenser microphone complement,
Type 100D
Octave-bandpass filter, Type 500B
Vacuum-tube voltmeter, Type 400A

(b) Response Measurement

Specimen response measurements are made using CBD-7 strain gages. The strain gages are located at highly stressed locations that are determined by experience in simple cases and by "stress coat" in more complex cases. Douglas feels that the use of "stress coat" is an excellent way to locate gages.

5. INTERPRETATION OF DATA

The main purpose of a test program is to

1. Establish a design type — configuration study.
2. Perform quantitative development tests of a structure — predict service life.
3. Perform proof test of a structure by a jet engine.

The data reduction techniques and the method of selecting stress test levels are based on an extended form of Miles' analysis developed by VanDyke, Belcher, and Eshleman.

As in Miles' work, the response of a panel is described in terms of a randomly modulated carrier whose envelope has a probability density in the form of a Rayleigh distribution. The carrier frequency corresponds to the first resonance of the test panel.

Since the probability distribution of stresses is the same for each test, the index of severity of an individual test is the rms stress — the most probable stress. Using the rms stress as the index of stress intensity it is then possible to develop an 'S-N' curve for random loading. This is done as follows:

If a test panel has a fatigue life of N cycles of the carrier, then the number n_i of those cycles lying in a narrow stress range can be taken as $P_i N$ where P_i is the probability that a stress lies in that range — given by the Rayleigh density function. Taking the mean stress of this narrow range and referring to an orthodox S-N curve, the number N_i of cycles to cause failure at this stress level is found. Assuming Miner's rule of linear accumulation of damage, the incremental damage (or the fraction of fatigue life 'used up') at this stress level is $\frac{n_i}{N_i}$ which is $\frac{P_i N}{N_i}$, thus the total damage is the

integral over the whole stress range (0 to ∞) of this quantity and is equal to unity. This gives a relation between the random fatigue life N and the orthodox S-N data in terms of the Rayleigh density function.

As already stated, this relation is in terms of an integral which contains two stress dependent quantities; to accomplish this integration, Miles assumed that stress and cycles-to-failure in the constant-stress-amplitude fatigue test are related by a simple power law. In the method developed by Douglas the integration is carried out numerically using experimental S-N data.

At this point it is possible to construct a 'random loading S-N curve' in which the stress level is the rms stress. A further S-N curve can be drawn in which the stress referred to is the "peak-damage stress". The concept of a peak-damage stress arises as follows: - high stresses contribute strongly to damage but they occur relatively infrequently, lower stresses contribute less strongly but they occur more frequently, consequently there is an intermediate stress level at which the damaging ability and the frequency of occurrence unite to produce the "peak-damage stress".

Since the damage contributed by a stress level S_i is $\frac{P_i}{N_i}$ the fractional damage is $\frac{P_i}{N_i}$; the value of stress for which this reaches a maximum is the peak damage stress.

Having constructed a random loading S-N curve, the next step is to predict the rms stress which will be experienced by a panel in its service environment. This is done by using Miles' formulation of the response of a single-degree-of-freedom linear system in terms of its resonance frequency, damping ratio, power spectral density of the excitation pressure in the resonance band, and stress response to a unit static load. Miles' formulation is extended by the inclusion of two factors one of which provides for the excitation of more than one mode in a test panel while the other is a correction to account for non-linearity of the 'stress response versus load' curve.

The analytical methods outlined above form the rational basis of the siren testing carried out by Douglas. Siren tests are primarily of two types, the first of these

being frequency-response explorations of a structure yielding data on resonance frequencies, damping factors, relative stress magnitudes, and stress-versus-load curves. These data are then used to compute multi-mode and non-linearity correction factors which can then be incorporated in the formal computation of the expected life in a given service environment. The actual computation is best accomplished by a very convenient nomograph entitled "Fatigue Life Design Chart-Random Loading" which is used to predict the allowable noise level for a given life. Rather than reproduce the nomograph exactly, its form and use will be described in general terms.

A 3-cycle by 5-cycle log-log grid is divided into six areas each of which introduces a different term into the 'computation', these terms are dynamic amplification factor, stress concentration factor, sound pressure level, static stress, random S-N property, and service life. The first and last named areas (the 'beginning and end' of the nomograph) are provided with frequency scales, while each area contains a series of lines corresponding to different values of the appropriate factor. In the prediction of allowable noise level one enters the nomograph simultaneously at each end (using the resonant frequency of the panel) and proceeds from zone to zone using the appropriate value of the corresponding factor until the paths intersect in the zone of sound pressure level where the allowable level is read off.

The second type of siren test is an accelerated test in which a short term (20-30 minutes) exposure to a relatively high noise level is used to measure or verify the expected life of the panel in its simulated service environment (jet engine test).

For this work a second nomograph has been constructed, entitled "Conversion Chart: Discrete Loading to Random Loading". Once again a six-zone nomograph is used, the factors introduced in the various zones being damping ratio, non-linearity, ratio of test noise-level to service noise-level (db difference) test life, service life, and multi-mode correction factor.

As before, the nomograph is entered simultaneously at each end (using the resonance frequency of the panel) and the paths intersect in the zone of noise-level ratio, thus yielding the test level for given conditions of service level and service life

and an arbitrarily chosen test life.

A variation of this method of accelerated testing is used in which the panel is exposed for a series of short periods (say 15 minutes at each major mode) to different levels until failure occurs; these levels increase in 3 db steps. The number of cycles of exposure at each level is known but the actual critical stress in the panel at each level is not known. However, the ratios of the different stress levels are known from strain gage readings. If a first approximation to one stress level is assumed, then all other stress levels are known; next, the fatigue life at each level can be found from an S-N curve, consequently the cumulative damage at each level is known (ratio of actual cycles to life) and the sum of these should be unity. A series of trials gives the proper value of stress level to yield a cumulative damage of unity. This then gives the correct relation between critical stress and (strain gage) indicated stress.

An arbitrary choice of critical stress (and its corresponding life) for a single-level test can then be converted to a corresponding measured stress. From an experimental stress/load curve the appropriate test-level can be found and the nomograph can be used to find an allowable service load for a desired service life.

6. TIME AND COSTS

The approximate cost of the siren facility is not available; however, the total cost of acoustic facilities including anechoic and reverberation room is one-half million dollars. The approximate cost of a test program on a given panel configuration is not available.

7. COMBINED ENVIRONMENT TESTING

No sonic fatigue tests have ever been made in combination with other environments. With some small modifications to the facility, specimens could be heated to a limited extent and they could be pressurized, but at the present time, no provisions exist for doing this.

8. BIBLIOGRAPHY OF RELATED REPORTS

SCHJELDERUP, H. C., and KARNESKY, A. L., "A Combined Analytical Experimental Approach to AIF," Shock and Vibration Bulletin, Part 2, Dec. 1957

Authors' Abstract

A sound survey of AR. B. 66, and AA3-D Aircraft is described including the techniques of instrumentation and presentation of data. Sources of error are discussed. Interpretation of this acoustical environment with respect to structural damage and repair is presented.

BELCHER, PETER M., VANDYKE, JOSEPH D., Jr., and ESHLEMAN, ARTHUR L., Jr., "Development of Aircraft Structure to Withstand Acoustic Loads", Institute of the Aeronautical Sciences, Volume 18, No. 6, June 1959

Authors' Conclusions

The development program for acoustically loaded structure for the DC-8 jet transport has been described. A summary of the analysis and test phases and their interrelationships has been given. New techniques of experimental stress analysis, using a high-intensity siren, have been outlined. The results of the siren test program, used in the design of the airframe structure, have been shown to be verified by accelerated tests of production structure under jet-noise loading.

The results of the program inspire confidence that a method of relatively inexpensive structural development has been established. With results of the requisite background of information and experience, airframe manufacturers can solve new design problems with comparatively little development cost and lead time.

ESHLEMAN, ARTHUR L., Jr., VANDYKE, JOSEPH, Jr., and BELCHER, PETER, "A Procedure for Designing and Testing Aircraft Structure Loaded by Jet Engine Noise", ASME Publication, Paper No. 59-AV-48, March 9-12, 1959

Authors' Abstract

A procedure developed by the Douglas Aircraft Company for design of structure loaded by jet-engine noise is outlined. A definite "tool" is provided which leads to the design of efficient structure. The limitations of the theory and their effects on the design procedure are considered. Some typical DC-8

structures which were developed by use of these techniques are discussed.

BELCHER, P. M., "Use of a High Intensity Siren in Fatigue Testing of Structure Subjected to Acoustic Forcing", Presented at Fifty-Second Meeting of the Acoustical Society of America, November 15, 1956

Author's Abstract

The problem of aircraft structural fatigue under acoustic forcing has led to a need for economical high speed destructive testing techniques. One such method, employing a high-intensity siren, is described here. A unit presently in use and one now under construction are discussed. A method for using data from this discrete tone test in fatigue design for structure subjected to random sound is outlined.

STRENGTH AND DYNAMIC STABILITY SECTION AND STRUCTURES SECTION, DOUGLAS AIRCRAFT COMPANY, "Results of RB-66 Acoustic Fatigue Proof Test Conducted in Alaska", Vol. I-II, Report No. LB-25765, June 2, 1958

Authors' Summary

A ten hour acoustic fatigue proof test was conducted on RB-66 AFSN 54-547 during the month of February 1958 at Eielson Air Force Base, Fairbanks, Alaska. The main purposes of this test were to prove that all modifications of the aircraft incorporated by ECP's 668, 708, 200-204 and 200-205 would be adequate for the life of the aircraft and to uncover other areas requiring modification. The test was conducted in Alaska because in the cold weather environment the engines powering the aircraft produce their maximum sound levels. In these higher sound levels, the ten hour test would be approximately equivalent to ten years of service life under standard day conditions. Results and Theory of the test are discussed in detail in the two volume report.

McCLYMONDS, J. C., and SOOT, H., Strength and Dynamic Stability Section, Douglas Aircraft Company, "Results of Acoustic Fatigue Proof Tests RB/B-66 Control Surfaces", Report No. LB-35382, October 18, 1956

Authors' Summary

A series of ten-hour acoustic fatigue proof tests were conducted during the period extending from June 23, 1958 to November 25, 1958 at the Douglas Long Beach facility. The purpose of these tests was to prove that

the redesigned aileron, elevator and rudder incorporated on the RB/B-66 series aircraft by ECP 200-247 would be adequate for the life of the aircraft. The tests were accomplished in a jet engine test cell with an Allison J71-A-13 engine providing the acoustic excitation. In order to provide a proper reference point for the tests, the test specimens were also installed on an airplane and the vibration response of the structure was measured while the engines were operated at maximum power on the ground.

SCHJELDERUP, H. C., McCLYMONDS, J. C., and BLANKENSHIP, C. E., Douglas Aircraft Company, "Structural Fatigue Caused by Jet Engine Noise on RB/B-66 Aircraft", Report No. LB-25187, October 18, 1956

Authors' Abstract

A description of the test program, its development, pertinent results, and recommendations for structural repairs are contained in this report which is presented in two parts:

1. Empennage control surfaces and speed brake fatigue induced by jet engine noise.
2. A complete survey of structural areas subject to critical fatigue damage caused by engine noise.

RADER, W. P., BELCHER, P. M., VANDYKE, J. D., and ESHLEMAN, A. L., Douglas Aircraft Company, "Load Computations used in Acoustic Fatigue Tests of DC-8 Structure", Report No. SM-23234, November 14, 1958

Abstract

This report provides a record of test load computations for fatigue tests and for assembly proof tests performed at the Sound and Vibration Laboratory of the Santa Monica Division on specimens of acoustically loaded DC-8 structural components. This is an abridged edition of the original report that contains a summary of the work performed with examples of the test method along with several typical structural panels that were tested.

VANDYKE, J. D., ESHLEMAN, A. L., and BELCHER, P. M., Douglas Aircraft Company, "Method for Designing and Testing Structures Subjected to Random Acoustic Load", Report No. SM22555, August 1, 1956

Authors' Summary

Two nomographs are presented in this report. The first is used to predict fatigue life of a structure subjected to random acoustic loads by using parameters that are determined from theoretical calculations, or preferably from simple non-destructive tests on actual or simulated structures.

The second nomograph is used to convert fatigue test life under discrete frequency acoustic loading to life under random acoustic loading. The assumptions from which the nomographs are derived are:

1. That the probability of obtaining a certain peak value of stress for each cycle of vibration follows a Rayleigh distribution, where most probable stress is a root-mean-square stress; and
2. That the cumulative damage theory of fatigue is valid.

In the past Lockheed has been concerned mostly with R & D work in the problem of sonic fatigue. Two WADD sponsored programs that have been completed are:

1. Correlation measurements of jet noise and structural response characteristics. Further studies along this line are continuing in Lockheed supported programs (See Section IV for brief discussion and WADD Publication TR-60-220).
2. The investigation of the effects of loading methods (random and ordered spectra) on fatigue life, and the comparison of various theories of cumulative fatigue damage.

At the present writing Lockheed is initiating plans and assembling facilities for sonic fatigue tests on C 141 Wing Panels. A siren with a 160 db power level coupled to a progressive wave horn is being used as the exciter.

Lockheed has a cold jet (3" diameter nozzle). This installation has been used for basic studies on jet noise generation and propagation. (See figure III- G-1) In the development stage is an airstream modulator capable of 2000 acoustic watts at frequencies up to 2500 cps.

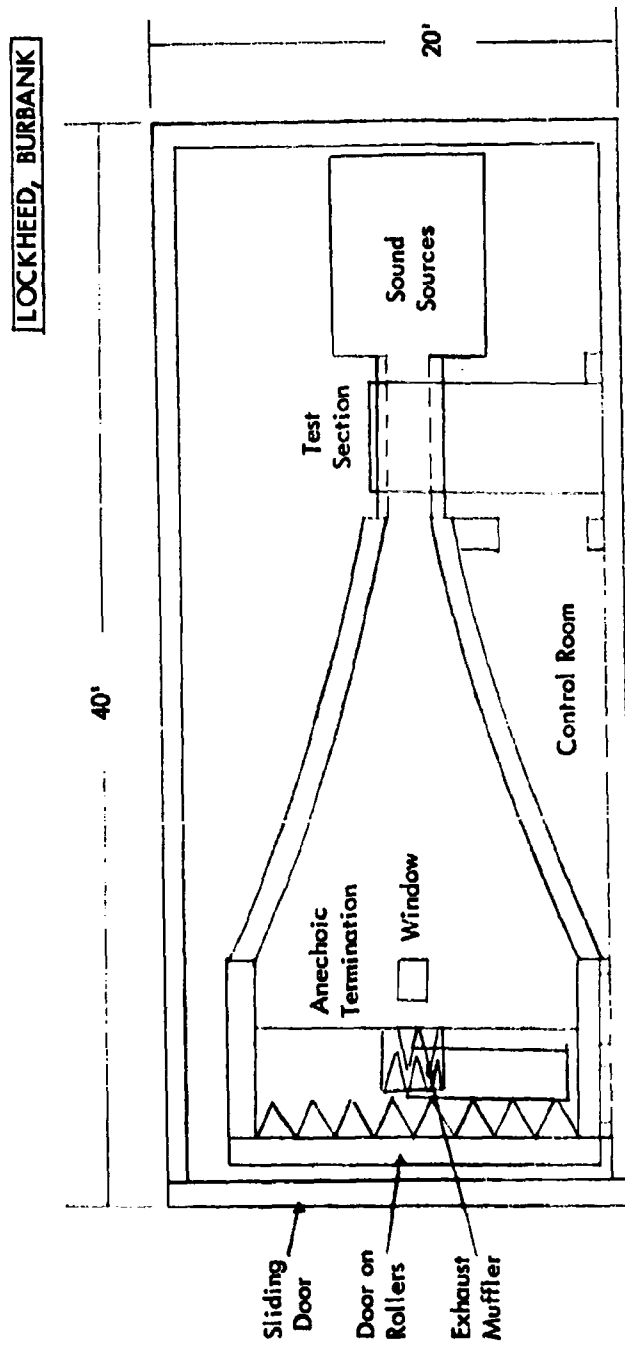
Plans for a sonic installation at Lockheed's new Rye Canyon Research Facility are in the final stages. (See figure III G-2 and III G-3) The choice of either sinusoidal or random fatigue testing is still under consideration. Lockheed feels that there is a need for both, and the new facility will have necessary diversification.

LOCKHEED, BURBANK



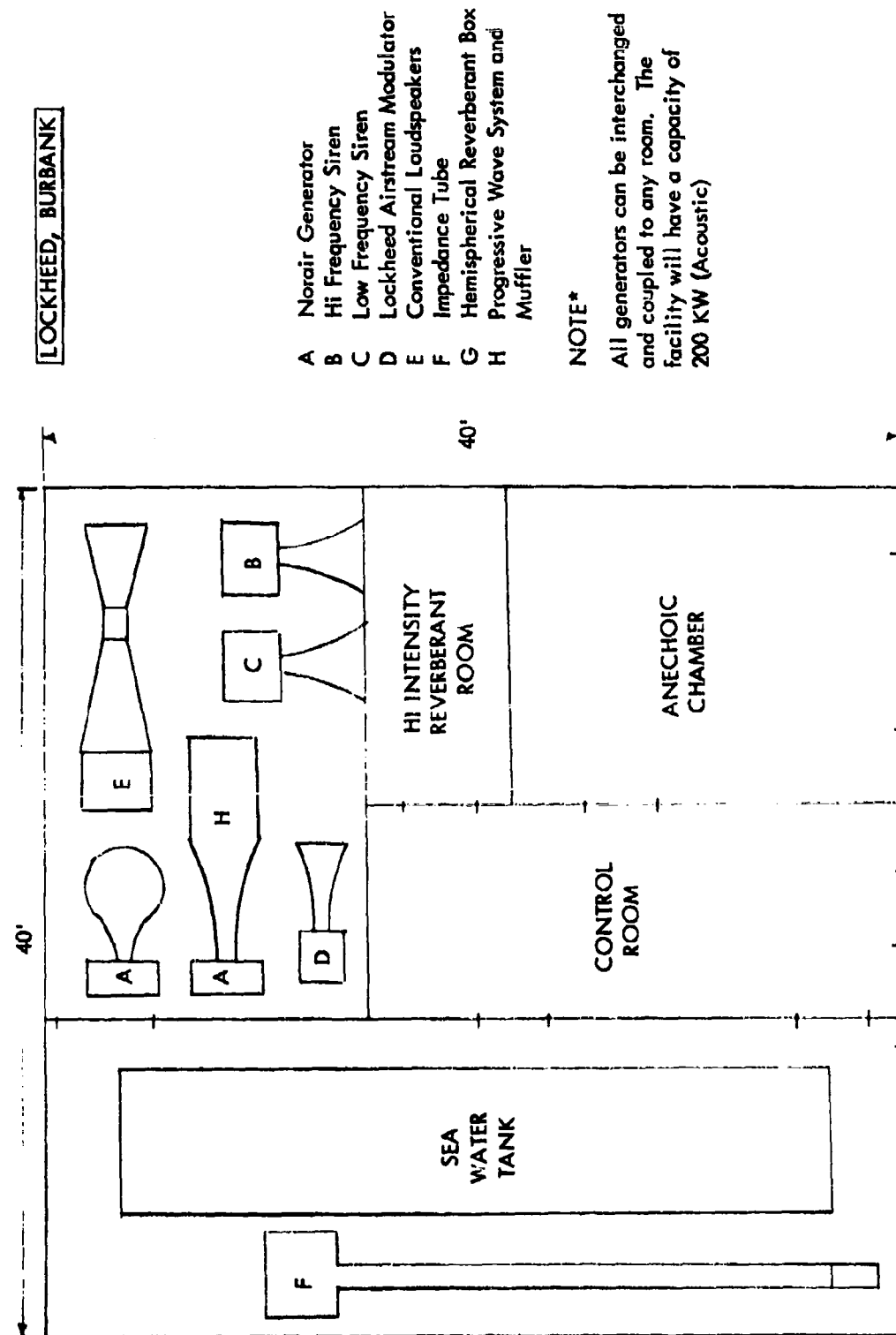
COLD AIR JET 3" DIAMETER NOZZLE

FIGURE III G-1



PLANNED HI-INTENSITY SOUND FACILITY

FIGURE III G-2



PRELIMINARY PLAN OF ACOUSTIC FACILITIES

FIGURE III G-3

1. GENERAL DESCRIPTION

In general, the existing facilities have been used to perform sonic fatigue tests of stiffened flat panels (approximately 150 different panel configurations) for a particular aircraft program (P6M flying boat). Discrete sirens and jet engines were used as noise sources. At the present time, Martin is designing a random noise facility that is expected to be in operation during the early part of 1961.

The major portion of Martin's work in the sonic fatigue testing has been related to the jet engine operation of the P6M series aircraft (the primary source of information on this work is Martin's Engineering Report No. 9784 dated November 25, 1957) and in this program three facilities were used:

(a) Siren Facility

Three high intensity sound generators have been used for testing the various structural specimens. The high intensity sound source consists of an air chopper and exponential horn. High pressure air (100 psi gage) passes through the air chopper at a rate from 130 to 150 cfm. Frequency is controlled by varying the speed of the chopper motor (General Radio 1702-A Variac controlled motor unit). The SPL at the mouth of the 30" diameter horn is controlled by varying the pressure. Each siren is enclosed in a separate acoustically insulated test chamber along with a steel rig to hold the specimen. Figure III H-1 shows one of the sirens with the horn attached.

(b) Jet Facility

Test panels were also exposed to the acoustic excitation of a J71 jet engine by mounting them on a steel frame (see Figure III H-2). Figure III H-3 shows a set up with two engine noise sources (this engine set up is no longer available at



HIGH INTENSITY SIREN

FIGURE III H-1

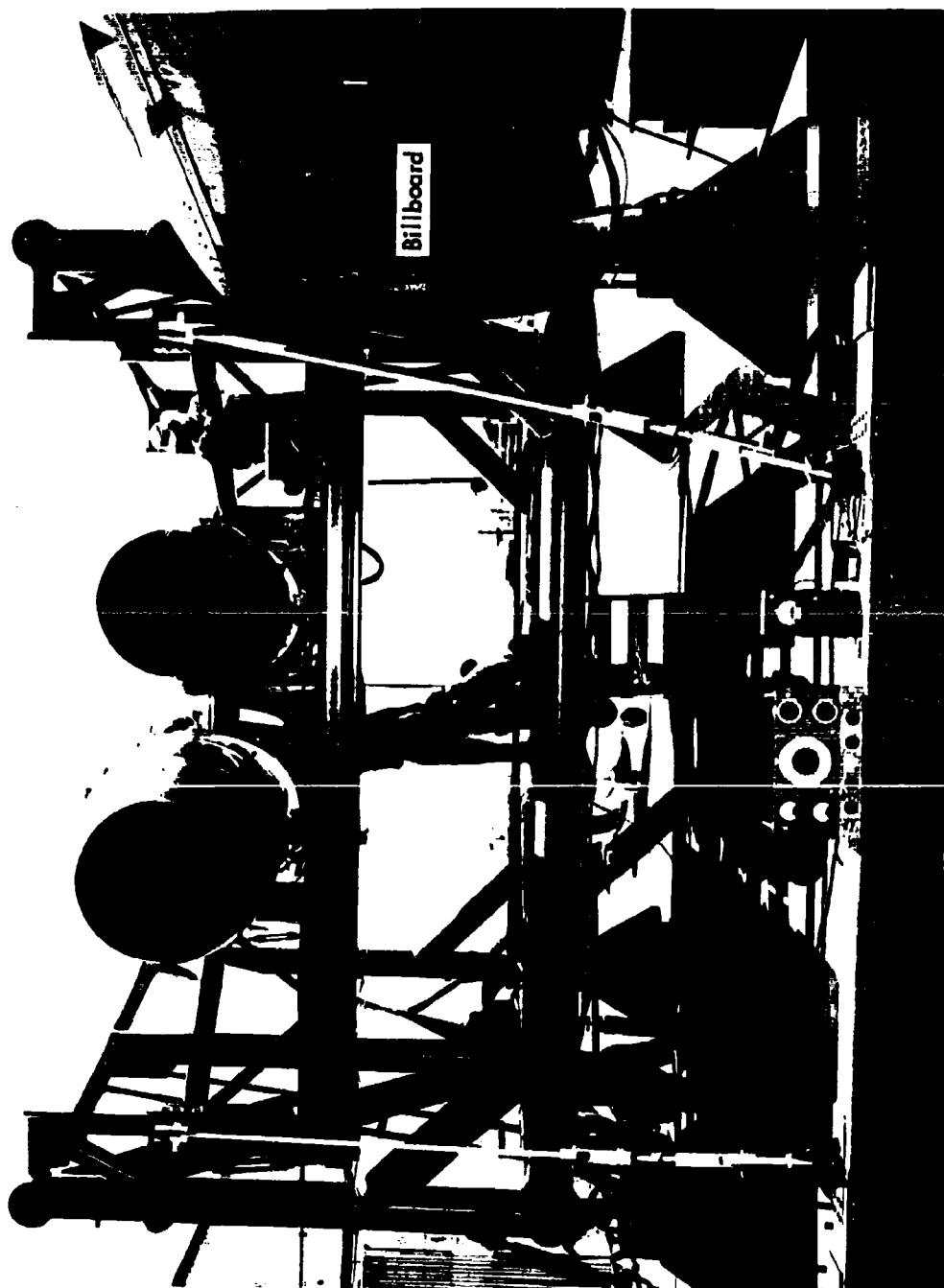
MARTIN, BALTIMORE



Specimen Mounting Frame

STEEL FRAME FOR JET FACILITY

FIGURE III H-2



JET FACILITY WITH TWO ENGINE NOISE SOURCES

FIGURE III H-3

MARTIN, BALTIMORE

Martin).

(c) Billboard Facility

A test set up called the Billboard Facility was designed and constructed to define the environment of the aircraft (YP6M-1 configuration). The billboard was essentially a reconstruction of the aft portion of the aircraft located behind a dual engine system to simulate approximately the sonic environment around the airplane. A section of the billboard is visible at the right in Figure III H-3.

2. TYPES OF SOUND SOURCES

The sound sources used at Martin include a discrete frequency siren and an AJ71 Jet Engine, and a broad band source is planned for the new facility.

(a) Discrete Siren

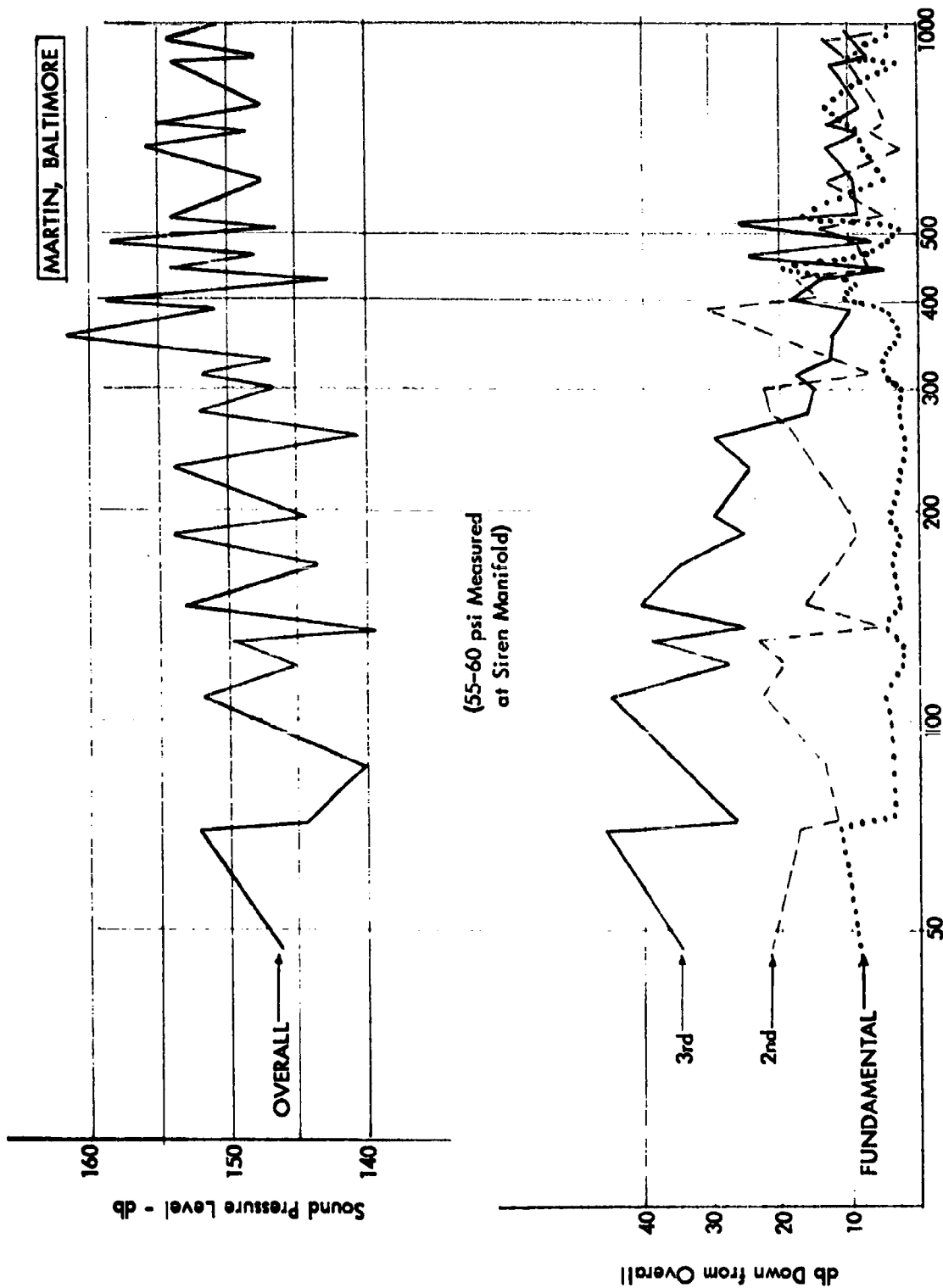
Three discrete frequency sirens are available for testing. Each siren terminates in an exponential horn configuration with an exit diameter of 30 inches. The useable frequency range is 100 to 3000 cps. The maximum sound pressure level at the mouth of this system is 160 db. Figure III H-4 is a plot of the fundamental frequencies of the siren versus the overall SPL, and the SPL of the fundamental, the second harmonic and the third harmonic (when the siren is operating at each fundamental frequency). Recently a 48 inch square exponential horn has been constructed to extend the low frequency range of the sirens to 50 cps. The chamber pressure of the sirens has been increased and maximum sound pressure levels with the new exponential connector is approximately 170 db.

(b) Jet Wake Panel Stand

A J71 jet engine was mounted to provide a means of exposing test panels to an approximate simulation of their operating environment. Figure III H-2 shows a typical test panel set up for jet engine testing.

(c) Random Noise Generator

The random generator will consist of 4 Altec Model 6786 air modulated



speakers terminated to a progressive wave test section. The test section will be 5 ft. x 5 ft. x 7 inches and will accept panel sizes up to 5' x 5'. The maximum predicted sound pressure level is 162 db broad band from 50 to 10000 cps. The facility has been in operation since 4-61; evaluation tests prove the capability to be as stated.

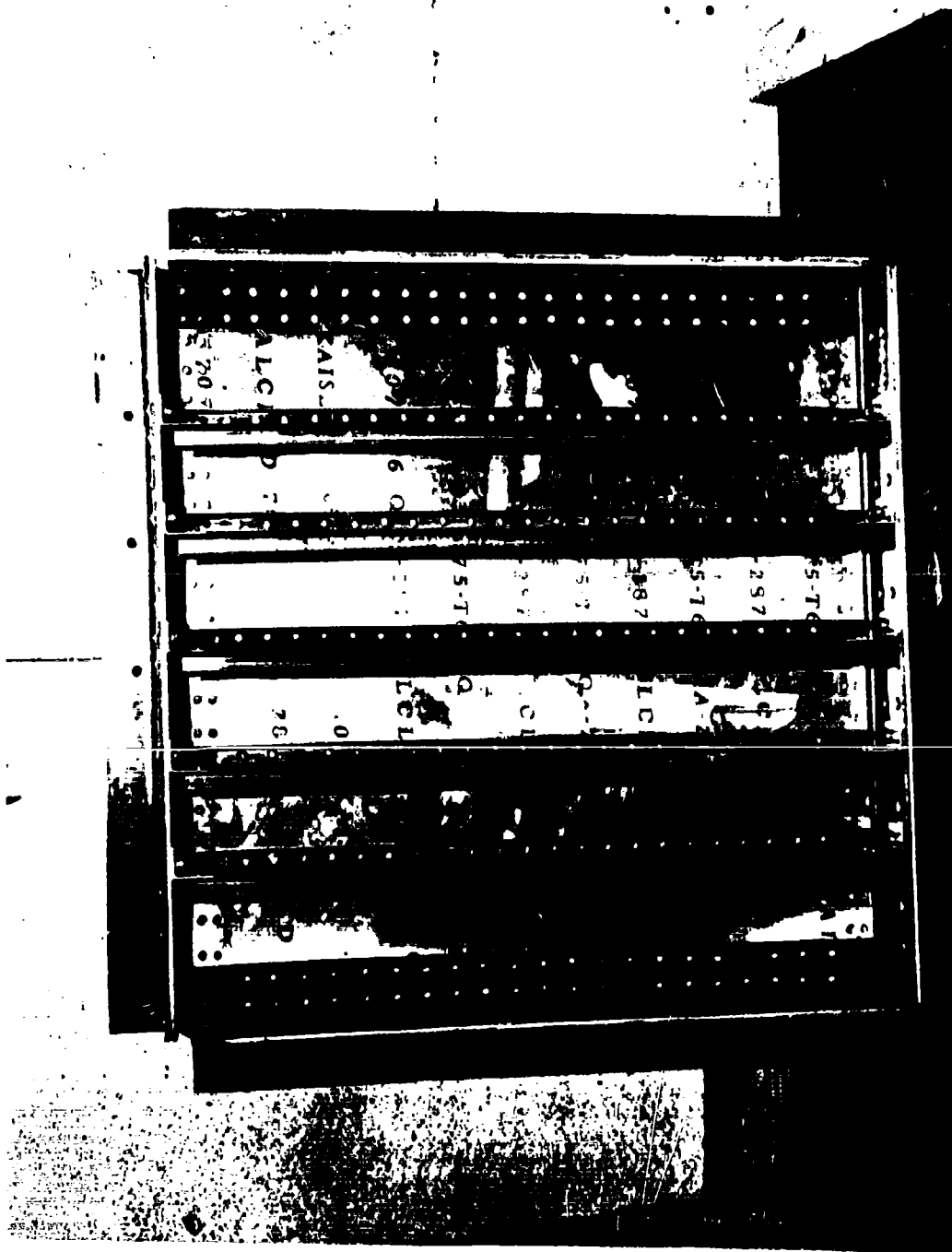
3. TEST METHODS AND SPECIMEN ARRANGEMENT

Siren test panels were tested at normal incidence to the sound. The resonant frequency of the panel was selected as that which produced maximum response in both the frames and the skin, and when more than one frequency produced large responses, the one which produced peak response in the frames was selected, since all but one aircraft failure had been in the frames or end attachment of the frames. A sound pressure level of 158 db was used in the testing because of the limitation of siren output over the frequency range of interest, and an arbitrary goal of 50 hours was set as a criterion for the test (this is calculated to be equivalent to a 50 hour exposure to a 163 db jet noise field). Panels under siren testing were inspected frequently (by stopping the excitation and examining the specimen) until failure occurred.

Test panels were constructed that simulated sections of the aircraft where failures occurred. Figure III H-5 shows a typical test panel. The frame length of this specimen was fabricated at something less than one-half of the actual length since the specimen size was limited by the test space available at the siren. The area between adjacent frames (bays) was considered to be the specimen test area. To reduce end effects a minimum of 5 bays was constructed. Specimens such as these were mounted on rigid frames and exposed to both jet engine and siren noise environments. Referring again to Figure III H-2, the frame mountings with specimens in place are shown for jet engine testing. These frames were designed to hold two 23" x 23" panels or one 33" x 33" panel.

4. INSTRUMENTATION AND DATA ACQUISITION

Figure III H-6 is a schematic diagram of the equipment and instrumentation in the siren test facility. Similar instrumentation for noise measurement and response

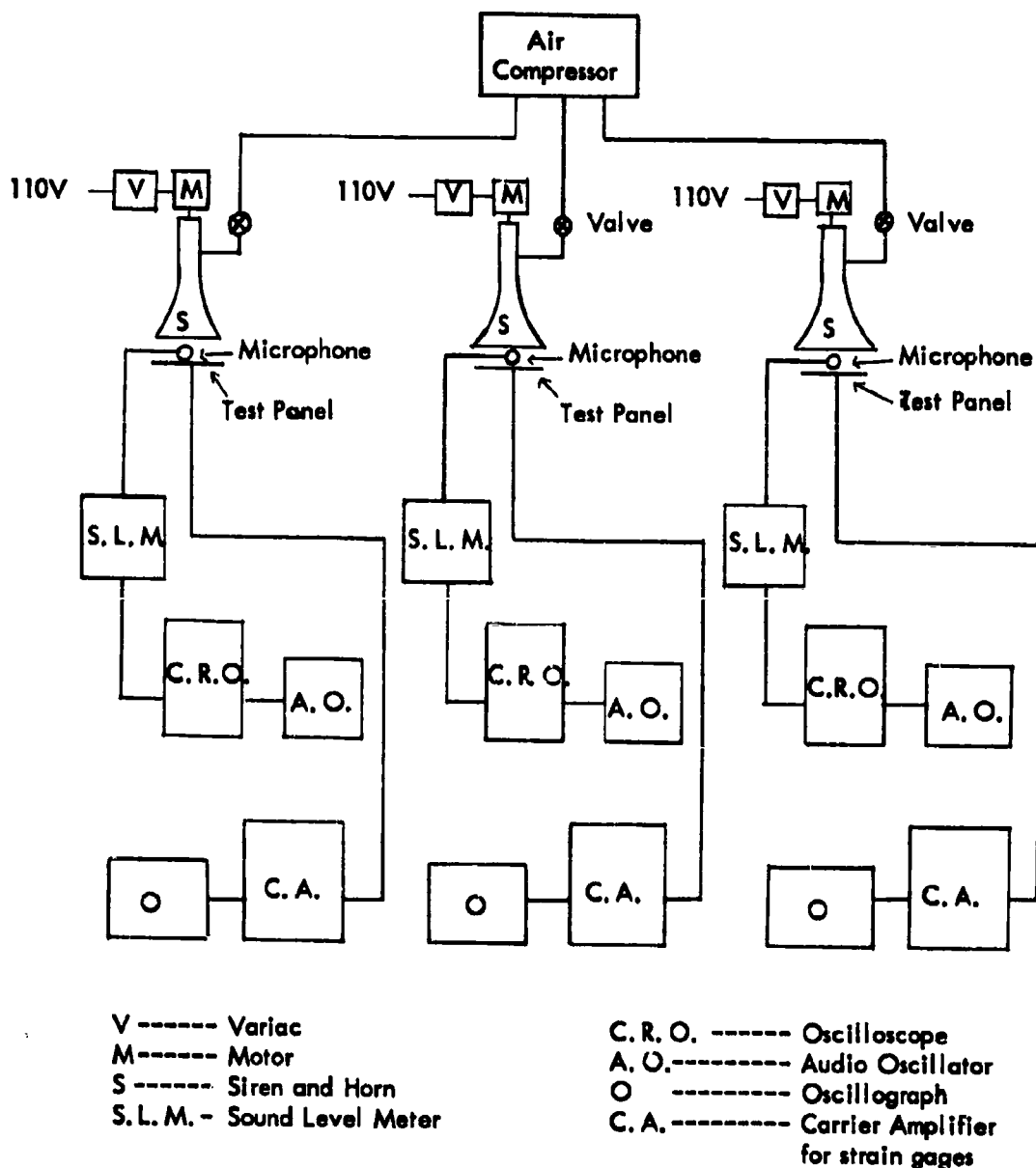


TYPICAL TEST PANEL

MARTIN, BALTIMORE

FIGURE III H-5

SCHEMATIC OF
SIREN TEST FACILITY



SCHEMATIC OF SIREN TEST FACILITY

FIGURE III H-6

was also used for jet engine testing.

(a) Noise Measurement

Sound pressure level was measured using Altec BR microphones and Massa Blast Gages Type 141 B in conjunction with a General Radio sound level meter. The frequency of excitation was determined by comparing the output voltage of the microphone system with the output of a calibrated audio oscillator using an oscilloscope to obtain a circular Lissajous pattern. Bruel and Kjaer one-third octave band analysis equipment was used for data analysis. If acoustic data were recorded, Ampex Fr100 tape recorders were used.

(b) Response Measurements

Each structural test panel was instrumented with Baldwin SR-4 Type A-8 strain gages at points where stresses or failures were expected to occur. There was an average of about 8 strain gages on each specimen. A Consolidated Electro-Dynamics Corporation "System D" carrier amplifier unit and an 5-119 recording oscillograph were used to record and monitor the outputs of the strain gages. Extreme lateral oscillations of the Z section frames were observed visually and by means of high speed (4000 frames per second) motion pictures.

In the case of jet engine testing, panel strain gage leads were cabled into a control shack and the recording system for both microphones and strain gage data was similar to that used in the siren tests as described above. The random outputs of the strain gages were recorded frequently on the oscillograph and the rms of the same random signal was read from the Ballantine meter.

5. INTERPRETATION OF DATA

Most of the sonic fatigue work performed in this facility was done in connection with the P6M noise program and this program had 3 major parts, a structural investigation, an equipment investigation, and a suppression investigation.

Of the three, the structural investigation is the most pertinent to the

SF testing problem, and, as conducted, consisted of the following parts:

- (a) The determination of the sound intensities on the P6M hull by means of measurements made along a hull structure during operation of the jet engines.
- (b) The comparison of the life of various modifications to the hull structure by means of siren tests on small panels representing the hull structure.
- (c) Exposure of test panels to the jet and siren noise field to determine the type and magnitude of response in order to establish a relationship between the time to failure in siren tests and the time to failure in the jet noise field.
- (d) Verification of noise and stress intensities on and in the actual aircraft by measurements during flight and ground testing.

The results of the panel tests using the siren were tabulated on summary sheets which included; panel number, time to failure, type of failure, panel description (dimensions, skin gage, type of frame, frame gage and spacing, and stabilizing member gage and spacing), frequency, and sound pressure level. Failure was defined as any visible crack in the basic structure. Approximately 150 panel configurations were tested and summarized. Throughout the testing program, various alterations were made to the panel types to improve their life.

The destructive testing carried out by discrete frequency sirens is related to the service life in the operating environment in the following way.

A preliminary test in a jet noise field is made to obtain the dominant modal response and the rms stress produced by the random excitation. This test is followed by exposure to a high intensity siren operating at the resonant frequency obtained from the jet engine test and measurements are made of the rms stress. Siren excitation is continued at its maximum intensity until failure occurs.

The problem is now to relate the siren test life at the corresponding rms stress to a predicted random noise life at the appropriate rms stress. It is to be realized that the stresses quoted are not the 'critical' stresses at the location of ultimate failure but are 'reference' stresses measured at some convenient location - it would be simply

fortuitous if the measured stress were the critical stress.

The next step is to obtain an orthodox (constant-amplitude) S-N curve and this is done by using a Sonntag driver to excite a specimen in reversed bending. This S-N curve can be quoted in terms of rms stress, or in dimensionless terms by dividing by the largest value of rms stress used in the test. The latter form, i. e. 'rms stress ratio' versus cycles to failure was the form used.

Using this curve it is now possible to construct a 'random S-N' curve as follows. The random behavior is assumed to be essentially that of a single-degree-of-freedom system, whose response has been shown (by Miles) to be in the form of a randomly modulated carrier whose envelope has a probability distribution described by the Rayleigh probability density function. The most probable value of stress is the rms value which can thus be used as an index of stress intensity in a given environment. If an environment produces an rms stress of σ and a fatigue life of N cycles of the carrier, then the number n_i of those cycles lying in a narrow stress range can be taken as $P_i N$ where P_i is the probability that a stress lies in that range. Taking the mean stress of this narrow range and referring to the previously found (orthodox) S-N curve, the number N_i of cycles to cause failure at this stress level is found. According to Miner, the incremental damage (or the fraction of fatigue life 'used up') at this stress level is $\frac{P_i}{N_i} N$. Now P_i is the small area under the Rayleigh density curve in the narrow stress range considered so that the quantity $\frac{P_i}{N_i}$ can be found as follows.

Divide the abscissa of the Rayleigh distribution into a number of stress ranges by suitable ordinates; find the area bounded by each pair of ordinates and the curve and divide this by the number of orthodox fatigue cycles corresponding to mean stress of this range. Following Miner's rule of linear accumulation, the total damage is then $(\sum \frac{P_i}{N_i}) N$ and is equal to a constant. The value of this constant is taken by Martin

to be .33 and the number of cycles N corresponding to an rms stress $\bar{\sigma}$ is thus

$$\sum_i \frac{.33 \cdot P_i}{N_i}$$

At this point there is available

- (1) Hours of life in the siren test
- (2) An orthodox S-N curve
- (3) The ratio of stress produced by the siren to stress produced by the jet
- (4) A random S-N curve

Using (1) with (2) yields an effective siren stress which, by using (3) can be converted to an effective jet stress; this last can be used with (4) to obtain an expected jet life.

The calculated life of the panels was to be compared with the observed occurrence of failure (cracks, etc.) in both ground and flight tests, but since the program was cancelled, this part of the project was not completed.

6. TIME AND COSTS

There were no figures available that could be used to determine the costs of performing tests in the various Martin facilities nor were the specimen costs available. Martin personnel felt that such information could be obtained but that it would entail considerable effort and cost.

7. COMBINED ENVIRONMENT TESTING

Martin, Baltimore, has no facilities for performing combined tests on acoustic fatigue specimens. Their present facilities could not be easily modified for combined tests, and they have no plans for running such tests in the future.

Combined high temperature and acoustic environmental testing of panels is in the planning stage at Martin-Baltimore.

8. BIBLIOGRAPHY OF RELATED REPORTS

THE MARTIN COMPANY - "Sonic Fatigue and Other Effects Resulting from Jet Engine Operation", Models YP6M-1 and P6M-2 - Engineering Report No. 9784 November 25, 1957

Author's Summary

This report describes the investigation of the vibration and associated fatigue problem in the P6M aircraft due to jet engine exhaust noise. Temperature problems arising from afterburner operation are also discussed.

Results are given of siren tests on structural panel to determine the necessary modifications for improving the life of the YP6M aft hull and empennage and to develop a more efficient aft structure for the P6M-2. A method of correlating siren and jet failure times at various noise levels is discussed and measured noise levels for the YP6M are presented. Also given are results of tests on P6M equipment items performed with mechanical shakers and by exposure to random and discrete noise.

The theory of noise suppression is discussed briefly and test results of one suppressor design are presented. No useable suppressor was developed.

The structural modification determined for the hull side of the YP6M involved converting the frames into members of symmetrical cross-section and adding longitudinal frame stabilizing members. Equipment mountings were revised to provide local frame stabilization where they attached to the frames and to employ additional vibration isolation devices. For other problem areas such as the crown and bullet, possible solutions were developed using low density plastic blocks for frame supports.

It was found to be necessary to express the correlation between siren and jet failure times in terms of a wide range of values, and thus final adequacy of the sonic fatigue modification will not be proved except by airplane usage.

The temperature problem was brought under control by canting the engines away from the hull side.

For future P6M type aircraft, the possible use of honeycomb panels or skin frames construction employing wider spaced extruded "I" frames appear to be promising.

III-1. THE MARTIN COMPANY
DENVER, COLORADO

1. GENERAL DESCRIPTION

The Martin Company, Denver has recently developed a large sonic fatigue facility to proof test components, structure, and in-silo liners for the Titan Missile Weapon System.

The facilities include random and discrete siren testing in outside open areas and in a reverberant chamber.

The sirens are supplied with air from an Allison TE-1 compressor. This compressor consists of 2 Allison T-56 modified turboprop engines coupled through a gear box to a compressor section from an Allison T-56 engine. Air may be supplied from this system to the noise sources at 65 psig and 20 lbs/sec. The random siren uses four electric motors to drive the counter rotating rotors and the discrete siren uses a 10 HP variable speed motor.

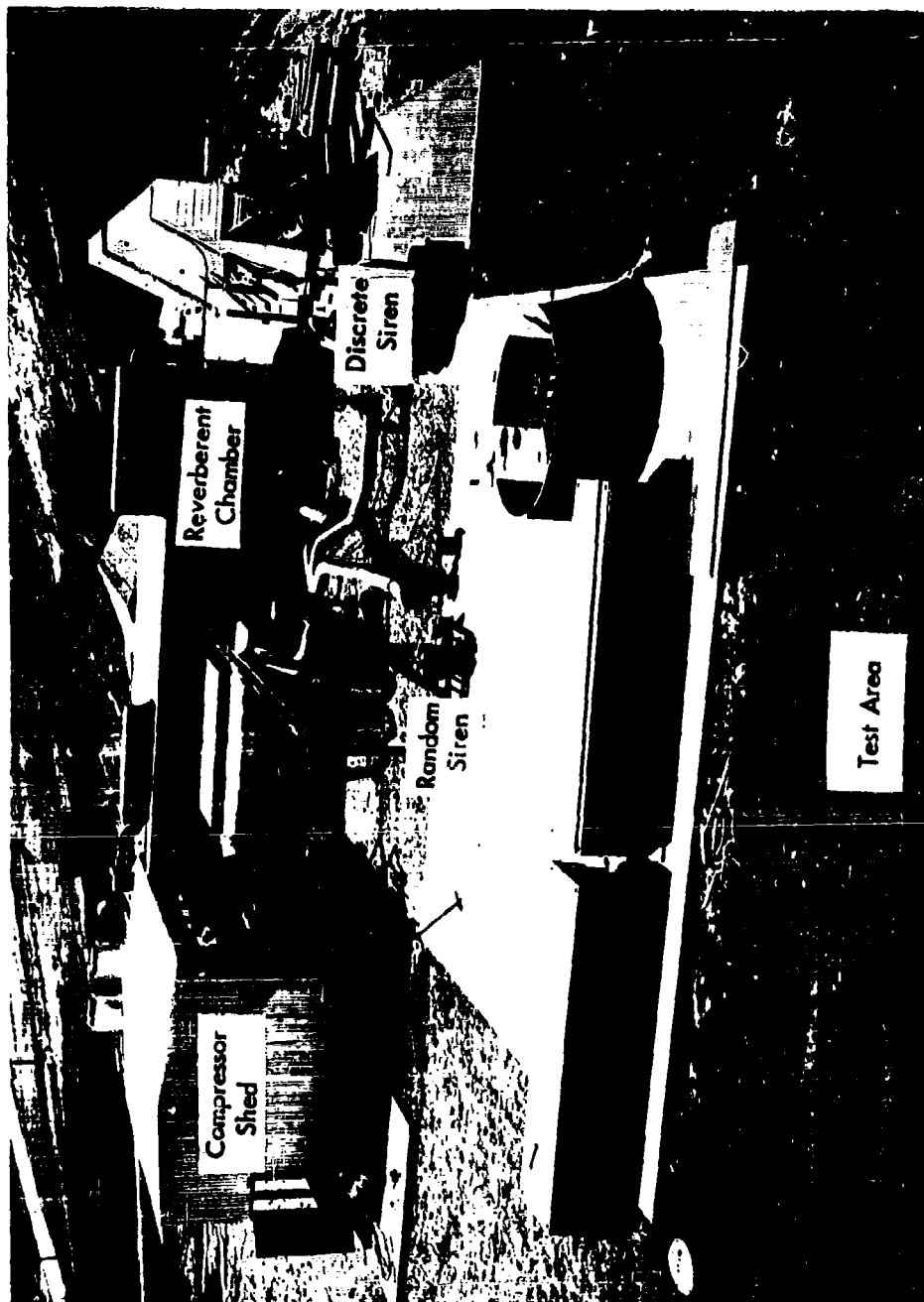
Figure III-1-1 shows the general test area and indicates the arrangement of the compressor shed, the reverberant chamber, the random siren, and the discrete frequency siren. Figure III-1-2 is a close-up of the random siren.

2. TYPES OF SOUND SOURCES

(a) Random Siren

Figure III-1-3 is a photograph of the random siren rotor assembly. This design is based on the type of wide band noise siren developed at the WADD Aero-Medical Laboratory (VonGierke, et al). Random acoustic energy is produced by the modulation of air flow through four counter-rotating rotors with randomly located ports. These rotors are belt driven from electric motors and the rotor speeds are selected to

MARTIN, DENVER



GENERAL TEST AREA

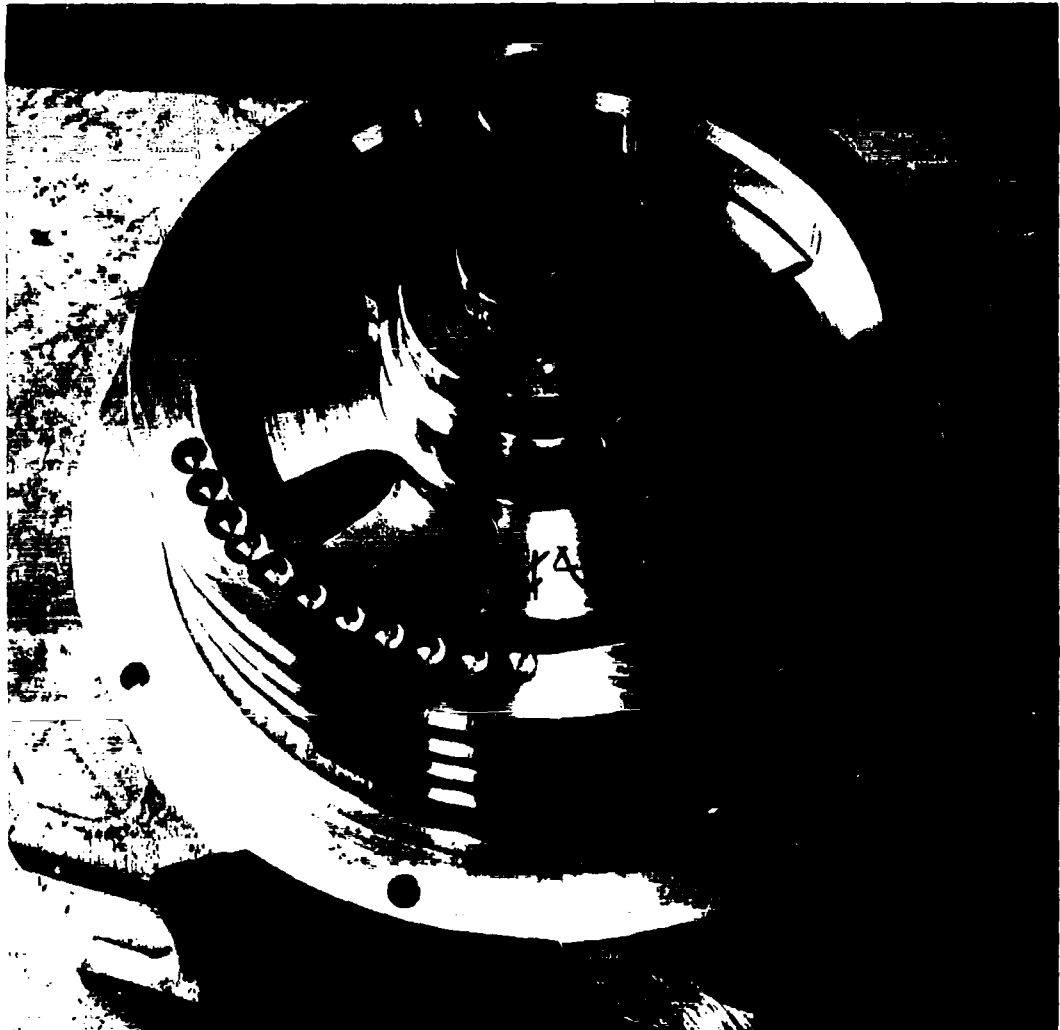
FIGURE III-I-1

MARTIN, DENVER



RANDOM SIREN

FIGURE III-1-2



RANDOM SIREN ROTOR ASSEMBLY

FIGURE III-1-3

produce various acoustic spectra, the energy content of which is proportional to the mass flow through the rotors. Extremely high mass flows (20 lbs per second at 65 psig) are required due to the inherent inefficiency of the siren.

The siren is connected to an exponential horn with a theoretical cut-off frequency of 22 cycles per second, and random noise levels in excess of 166 db overall over a 9 square foot section of the specimen have been obtained with this horn. Figure III-1-4 is a one-third octave band plot of the sound produced by the random siren. Figure III-1-5 is a narrow band (5 cps) analysis of a single random siren and of two random sirens set up in parallel using the same air supply. Figure III-1-6 shows the sound pressure level (as measured at the mouth of the horn) versus inlet air pressure for the single and parallel sirens generating into free space, for the single siren generating into a 74 cubic foot reverberant chamber, and for the single siren placed against a structure. For short time exposure testing (as short as 10 seconds) a quick acting by-pass valve in the siren air supply has been designed to shut off the excitation in one-half second.

(b) Discrete Siren

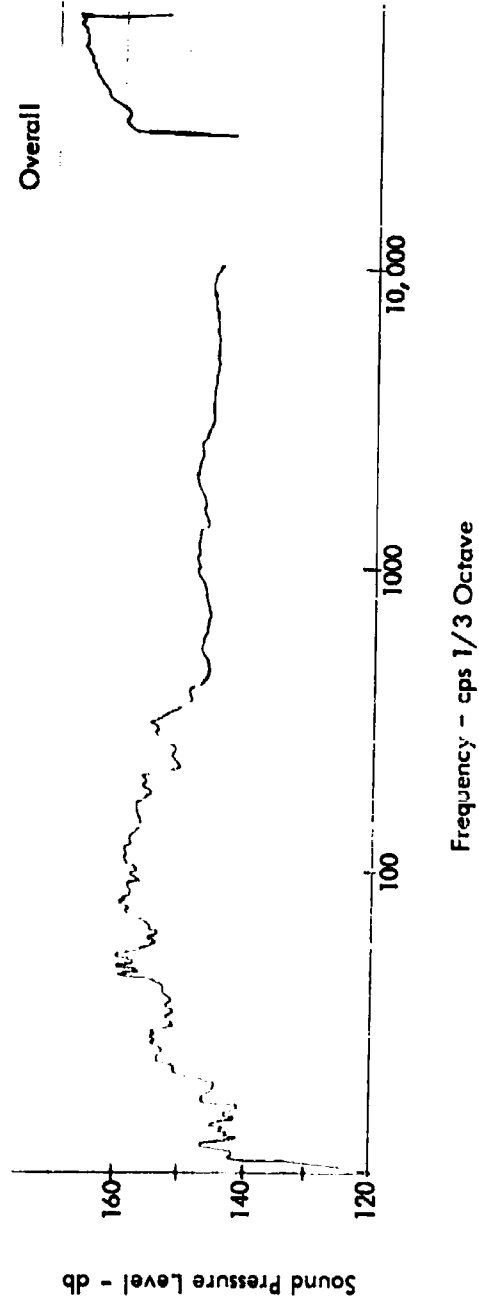
This siren, similar to others designed by Leonard and Rudnick, is preceded by a spherical plenum chamber. Figure III-1-8 shows the maximum performance of the siren as a function of frequency. When the siren is coupled to an exponential horn with a mouth area of 9 square feet, levels as high as 172 db have been reached. Most recently, the discrete siren has produced sound pressure levels of 160 db (30 to 1000 cps) over a 55 square foot area. The 20 port rotor of the siren is belt driven by a variable speed 10 HP DC motor and the air flow requirements are approximately 10 lbs per second at 40 psig.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

An outline of the method used to test structural segments of the Titan

MARTIN, DENVER

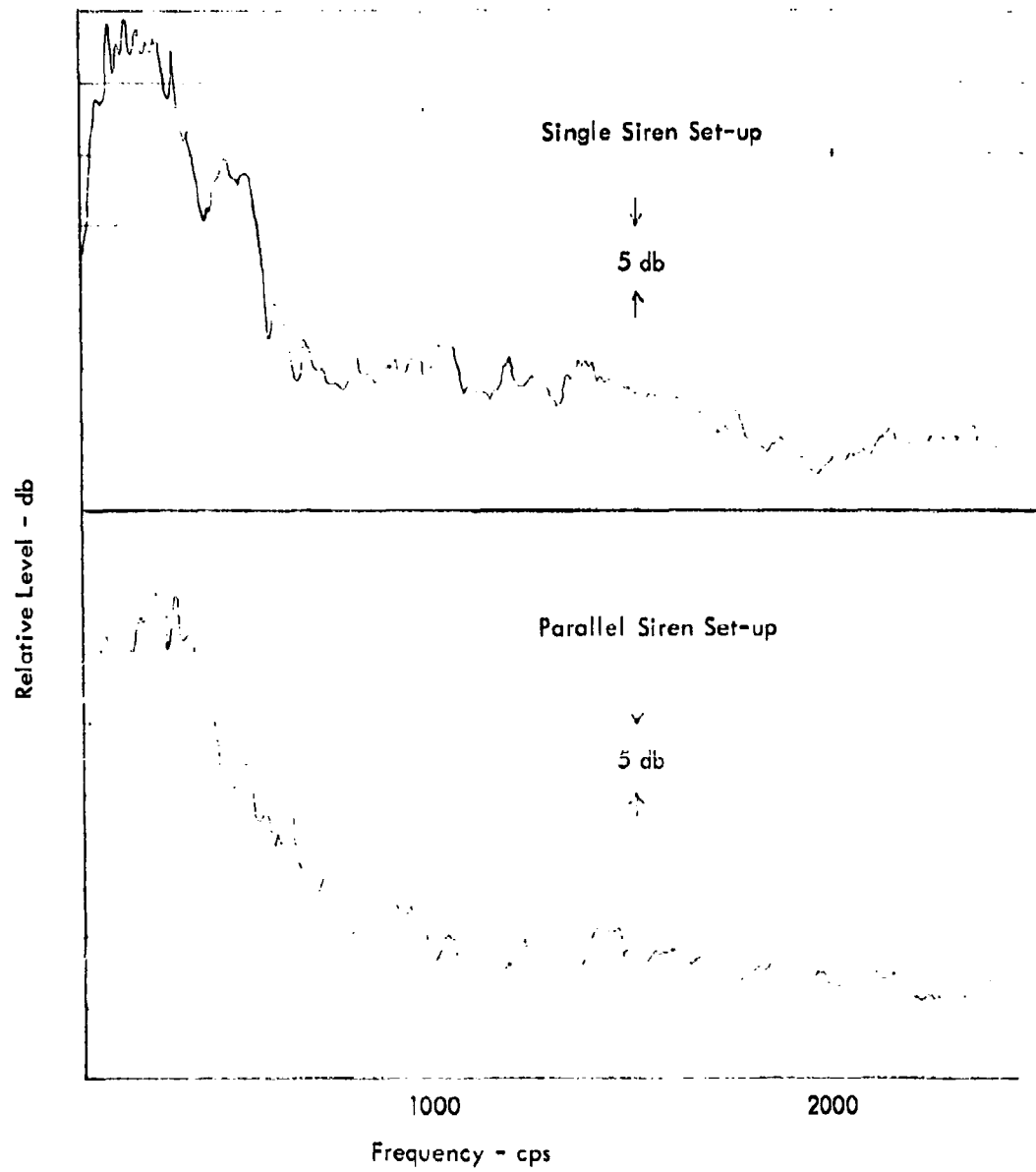
RANDOM SIREN SPECTRUM



RANDOM SIREN SPECTRUM

FIGURE III-1-4

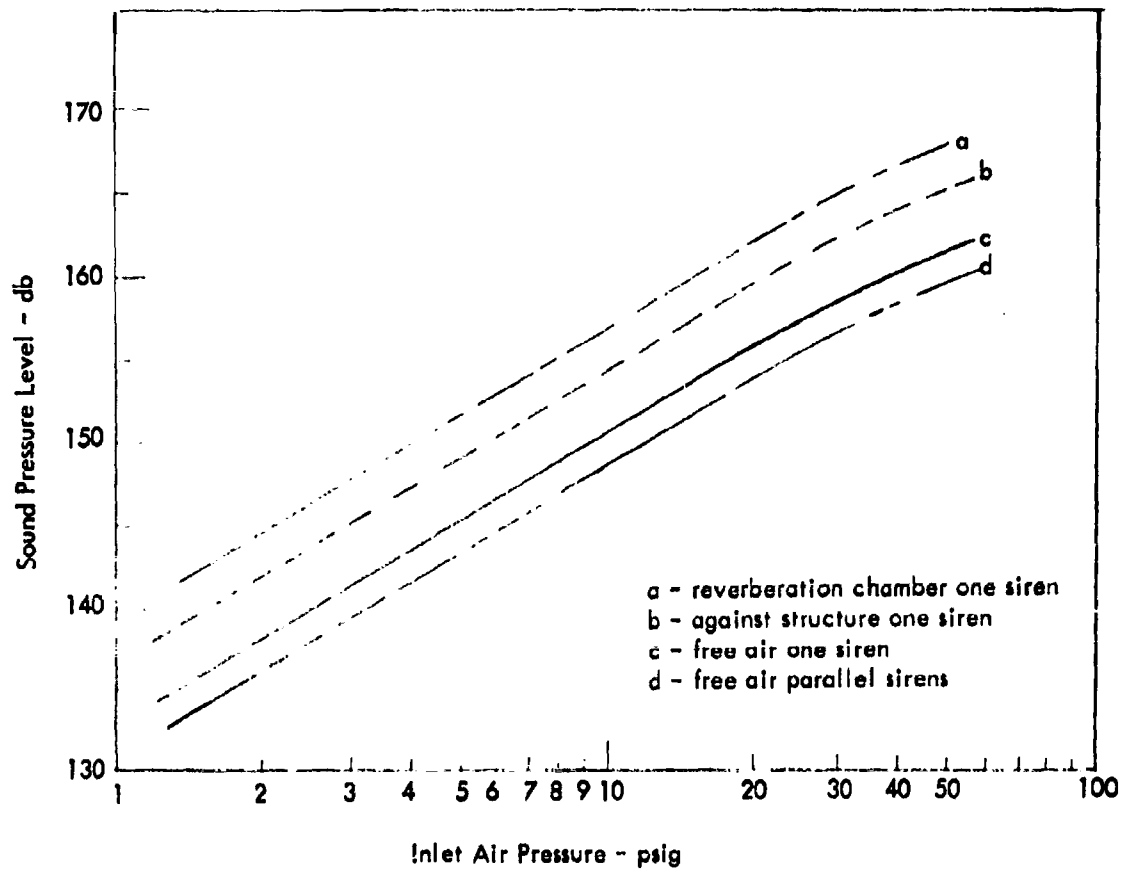
MARTIN, DENVER



NARROW BAND - 5 cps
ANALYSIS OF RANDOM SIREN

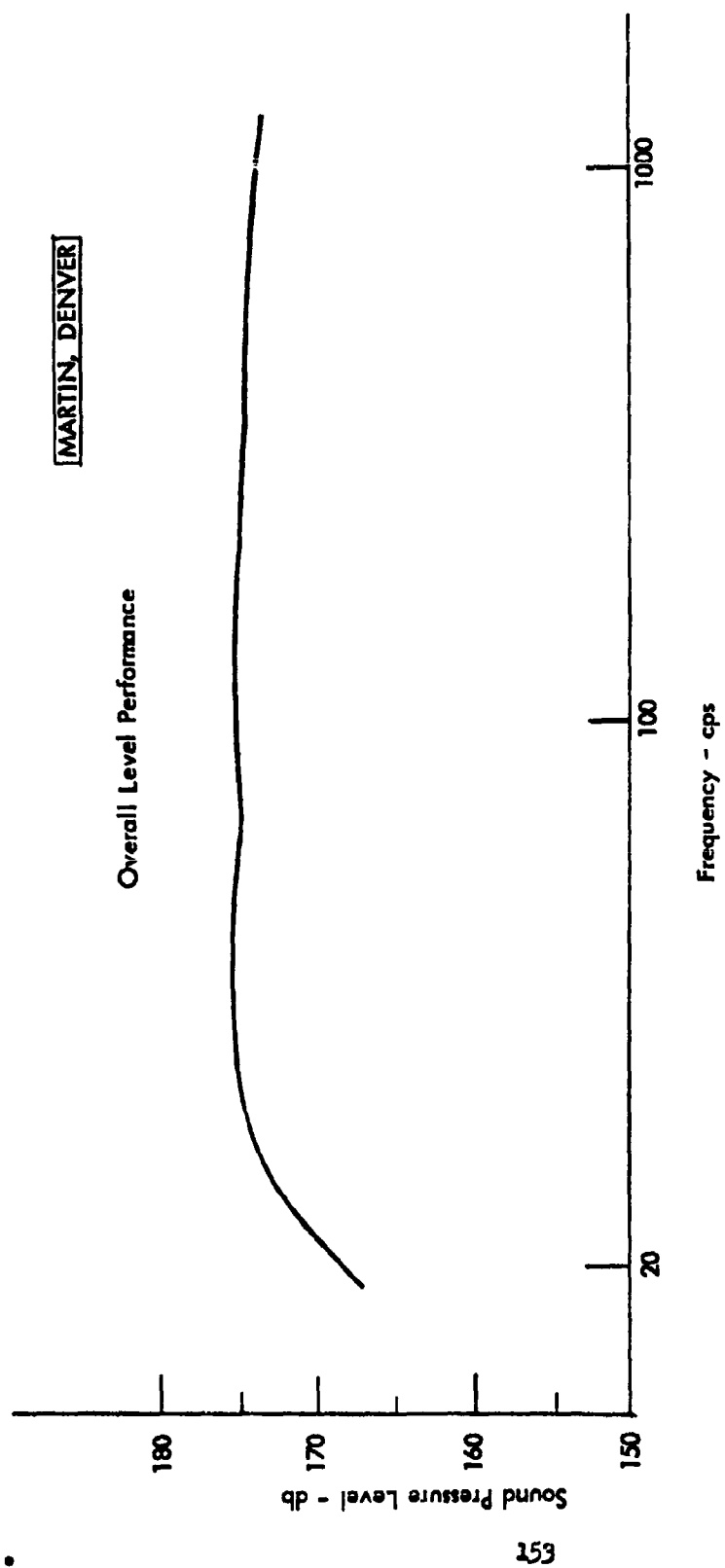
FIGURE III-1-5

MARTIN, DENVER



RANDOM SIREN PERFORMANCE
SINGLE AND PARALLEL ARRANGEMENT

FIGURE III-1-6



DISCRETE FREQUENCY SIREN

FIGURE III-1-8

Missile with the random siren is as follows:

1. The siren is calibrated against a high impedance surface (concrete block) to adjust, within limits, the SPL and acoustic spectrum to some desired values.
2. The siren is then placed so that it irradiates the test specimen with normally incident sound. The same distance is maintained between siren and specimen as was kept during the calibration.
3. The specimen (missile segment) is then statically pre-loaded to its actual operational strain level.
4. The instruments (microphone, strain gage, accelerometers) are calibrated and the calibration signals are recorded on magnetic tape.
5. The specimen is subjected to the siren noise for 30 second intervals until a total test time of 10 minutes has been accumulated or a failure has occurred.
6. A post test instrument calibration is made and recorded on all instruments.
7. A test of the siren calibration on the concrete block is repeated as a check.

The test program calls for seven full scale critical structural segments to be tested with the random siren. These segments are to be statically loaded to simulate actual structural loads in the missile. Figure III-1-9 is a photograph of a missile section in position for testing by the random siren.

Unfortunately, detailed reports that discuss the philosophies of testing with the random and discrete siren have not yet been released by the Air Force Ballistic Missile Division (See Section 8).

4. INSTRUMENTATION AND DATA ACQUISITION

For structural segments and panel tests, measurements and recordings of the following items are made: strain, acceleration, sound pressure, static loads, temperature, time base, and voice annotation. A block diagram of the test instrumentation is shown

MARTIN, DENVER



Missile Segment

STRUCTURAL TEST SET-UP

FIGURE III-1-9

in Figure III-1-10.

Strain is measured by uniaxial and biaxial strain gages and recorded on magnetic tape. The instrumentation for the strain gages consists of bridge balance networks, amplifiers, and step attenuators. A maximum of 6 strain gage outputs can be monitored on a C. E. C. oscillograph recorder for on-the-spot test evaluations.

Acceleration is measured with crystal accelerometers connected to Endevco Type 2614 amplifiers and recorded on tape. A network patches the accelerometer circuit outputs into a one-third octave analyzer to monitor rms g-levels during a test.

Sound pressure level is measured with Altec-Lansing 21BR Series condenser microphones and recorded on tape. A patching network is also available here to monitor microphone outputs.

Static axial loading is measured with 4 bridge-type load cells mounted at the loading jack heads.

Temperature around the specimen is made by the use of two thermocouples and recorded on a continuous recorder. Two additional channels of temperature record the ambient test conditions at the opening of the siren horn during the test.

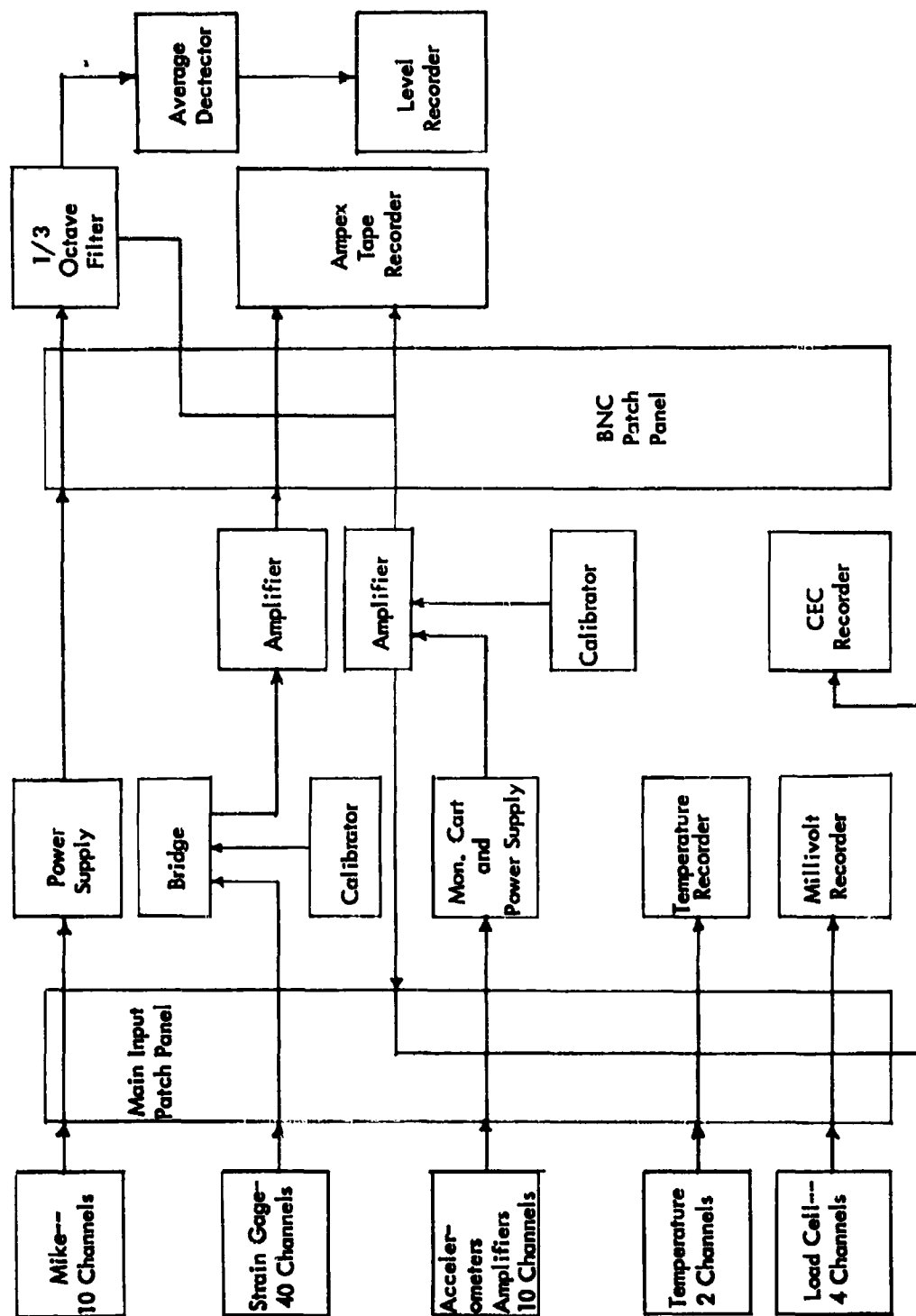
The duration of a test is recorded to the nearest one-tenth of a second on a magnetic tape recorder.

There is instrumentation for facility control and calibration, but details of this was not available in time for this report.

5. INTERPRETATION OF DATA

The primary purpose of the sonic fatigue program at Martin, Denver is to proof test missile structure and components, and silo liners for the Titan Missile Weapons Systems. They are also interested in determining the magnitude and frequency content of the response of the missile structure to the acoustic test environment.

Acoustic, vibration, and stress data are recorded during the structural tests and overall rms levels are measured. The data are presented as graphs showing one-third octave band and sometimes the spectrum level (1 cps bandwidth) of the rms sound pressure,



MARTIN, DENVER

STRUCTURAL TEST INSTRUMENTATION

FIGURE III-1-10

stress, and acceleration.

When a structural failure occurs, a time history plot of the stress and acceleration levels occurring at, or as near as possible to, the area of failure is presented.

In fatigue tests of missile structures, segments of the structure are tested with localized high-level random acoustic excitation. This test condition is not the same as would exist in a silo where the entire missile (or a good part of it) is exposed to the noise, and the test SPL must be adjusted to account for this fact. The test level is arrived at in the following way:

If the missile structure is considered to be made up of n segments or regions all subjected to the same pressure level p when in the silo, then the response (rms) in the r^{th} region due to this pressure in the s^{th} region is A_{rs} where A_{rs} is an influence coefficient relating pressure and response (as measured by, say, acceleration). These coefficients are found by measuring the response in the n regions when one region is excited (e. g. if region 1 is excited then measurements in the other regions give A_{11} , A_{21} ---- A_{n1}); it is assumed that reciprocal relations hold, i. e. $A_{rs} = A_{sr}$. If all regions are excited simultaneously by the same pressure p then contributions to the response in say region 1 are $A_{11}p$, $A_{12}p$, ---- $A_{1n}p$ but by the reciprocal relation these are $A_{11}p$, $A_{21}p$, ---- $A_{n1}p$ and these coefficients have already been found. Assuming the net rms response in region 1 to be the square root of the sum of the squares of the various contributions gives

$$p \sqrt{(A_{11})^2 + (A_{21})^2 + \dots + (A_{n1})^2} = p \sqrt{\sum_k (A_{k1})^2}$$

If a test level P applied to region 1 alone is to produce the same response, then $A_{11}P$ must equal

$$p \sqrt{\sum_k (A_{k1})^2}$$

$$\text{or } P = P \frac{\sqrt{\sum_k (A_{k1})^2}}{A_{11}}$$

hence,

$$\text{db (localized test)} = \text{db (silo)} + 20 \log_{10} \frac{\sqrt{\sum_k (A_{k1})^2}}{A_{11}}$$

This test pressure is applied to a localized region for a period of 10 minutes.

In the case of the Titan Missile the structure was excited with random acoustic excitation over a nine square foot area at a sound pressure level of 166 db. This level was used to minimize the possibility of fatigue of the structure during the test. The acoustically induced acceleration occurring on the remaining nine square foot areas of the structural segment was recorded on tape. A one-third octave analysis of the data was performed and the average acceleration level in one-third octave bands for each of the nine square foot areas was computed. Results of this test indicated approximately a 6 db difference in the acceleration response between localized and complete acoustic excitation for the structure tested.

The structure was then proof tested at 166 db with the static load on the structure programmed to simulate the dynamic loads during silo launch. After 10 minutes of testing at this level, no significant failures were observed which would affect the flight of the missile.

6. TIME AND COSTS

The cost of a structural segment for test purposes is approximately \$3000, and the estimated facility operating cost per hour (including an approximate figure for overhead) is \$110.00. For a given structural segment, a three day time period is allowed to complete the test. This consists of 2-1/2 days of set up time and 1/2 day to test. The cost of the entire facility is approximately \$630,000. The breakdown is

as follows:

Brick and Mortar	\$200,000
Compressors	270,000
4 Sirens	40,000
Instrumentatio .	120,000

7. COMBINED ENVIRONMENT TESTING

At the present time, no provision is made for combined sonic fatigue tests with other environmental tests. It is felt, however, that provision could readily be made to make combined tests of sonic fatigue and high and low temperature.

8. BIBLIOGRAPHY OF RELATED REPORTS

McGREGOR, H. N., "Test Plan In-Silo Launch Acoustic Program", March 1960

Author's Summary

This test plan describes a four-part test program designed to procure environmental and missile component response data to:

Predict acoustic and vibration environments in a missile launching silo during the launch period;

Predict the responses of missile functional and structural components to the predicted silo acoustic and vibration environments;

Design a silo wall liner capable of reducing ambient acoustic noise to levels non-detrimental to the missile system.

The test program is divided into four test projects:

Design, fabricate, and test launch-duct-acoustic-liners;

Determine the fragility levels of missile components and systems;

Determine the responses of selected missile structural segments to high intensity random noise and investigate the adequacy of the segments to withstand such excitation at levels expected in silo-launch-ducts;

Measure the acoustic and vibration levels on and in the vicinity of missiles in captive firing tests at the Denver test stands.

THE MARTIN COMPANY, "In-Silo Acoustics Program", Volume I - Component Testing, Volume II - Liner Testing, Volume III - Missile Structural Segments Acoustic Testing, 1960

Comments

These reports appear to be very pertinent to the facilities used at Martin, Denver. These have been requested from the Air Force Ballistic Missile Division, but they have not been received in time for a discussion to be included in this report.

1. H. Williamson, D. Dinicola and H. McGregor: Missile Structural Segments Acoustic Test - Silo Launch Technical Investigations Final Report. The Martin Company, Denver, CR-60-22 (Vol. 3), August, 1960.
2. W. P. Rader and H. McGregor: "Acoustic and Vibration Test of Lot VS Stage I Transition Section." The Martin Company, Denver, Colorado.
3. J. M. Otera and H. McGregor: Missile Component Acoustic Testing - Silo Launch Technical Investigation Final Report. The Martin Company, Denver, Colorado, CR-60-22 (Vol. 1), August, 1960.
4. J. M. Otera and R. A. Vigil: Component Vibration Test Silo Launch Technical Investigations Final Report. The Martin Company Technical Report, CR-60-22 (Vol. 2), August, 1960.
5. R. Pitsker and H. McGregor: Silo Liner Acoustic Testing - Silo Launch Technical Investigation Final Report. The Martin Company Technical Report, CR-60-22 (Vol. 2), August, 1960.

III-J. McDONNELL AIRCRAFT CORPORATION
ST. LOUIS, MISSOURI

1. GENERAL DESCRIPTION

Their facilities consist of a discrete frequency siren and a modulated air flow transducer with an associated chamber. McDonnell is also developing new transducers of the modulated air flow type for the acoustic facility. The existing facilities have been used to evaluate the effects of high intensity noise on flight vehicle structures (F4H Airplane and Mercury Capsule), fasteners, and electronic packages and components.

The majority of acoustic tests at McDonnell is conducted in a chamber 12' x 8' x 11' high. This chamber has an access door at one end 7' wide by 6-1/2' high. The chamber and access door are lined with two layers of acoustic insulation (high-absorption-coefficient) and two alternate layers of plywood to reduce the sound transmitted through the chamber walls into the surrounding area.

The compressed air supply presently used with the transducers consists of an Ingersoll-Rand type XRE compressor rated at 800 lbs per minute at 100 psig. The air supply used with the McDonnell polysonic wind tunnel is being considered for future use. This supply provides 20 lbs per second at 625 psi and has a storage capacity of 40,000 cubic feet at 625 psi at temperatures of 100° F. to 350° F.

2. TYPES OF SOUND SOURCES

The two types of sound sources used are a discrete frequency siren and a modulated air flow transducer. Limited work has been done with small cold air jet noise generators (approximately 160 db broad-band noise).

(a) Discrete Siren

The siren is attached to an exponential horn that has a mouth diameter of 30 inches. The frequency range is claimed to be from 150 cps to 6000 cps. Sound pressure levels of 170 db have been measured at the mouth of the horn. Figure III J-1 is a photograph of the arrangement in the acoustic test chamber.

(b) Modulated Air Flow Transducer

This transducer generates a broad-band noise (150 cps to 2000 cps) and levels of 150 db have been measured at the mouth of a 14" diameter horn. This source is used for testing electronic components and packages.

Detailed tests of maximum sound pressure level as a function of frequency and harmonic content of the siren, and spectral density of the air stream modulator have not yet been completed.

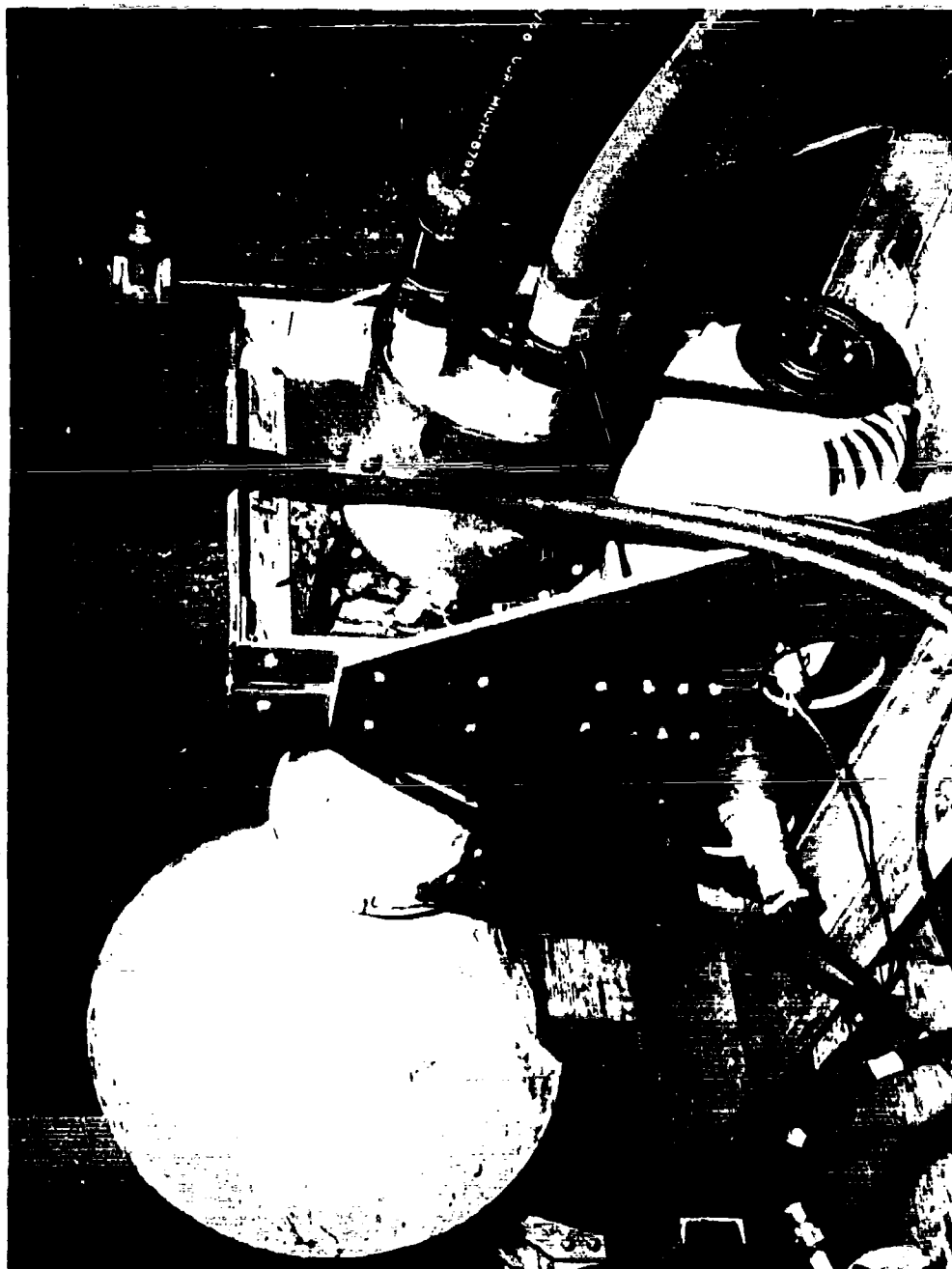
3. TEST METHODS AND SPECIMEN ARRANGEMENT

In the structural evaluation tests, the usual procedure is to first determine the resonant frequencies of the specimens. The specimen is then subjected to a high level at the frequency or frequencies considered most likely to induce failure.

The test structures are fabricated in a form to simulate, as closely as possible, the actual structure service installation with respect to the boundary conditions and fasteners used in the test specimen. The specimen size at maximum output of the sound source is limited to the diameter of the horn used (30" maximum). A typical test set-up is shown in Figure III J-2. Up to the present, only normal incidence testing has been used for structural tests.

4. INSTRUMENTATION AND DATA ACQUISITION

Table III J-1 is a listing of the instrumentation available for acoustic fatigue tests. Figure III J-3 is a block diagram showing the relationship of the sensing devices to the various recording and data reduction systems that can be used. Consideration



HIGH INTENSITY SIREN

McDONNELL, ST. LOUIS

FIGURE III J-1



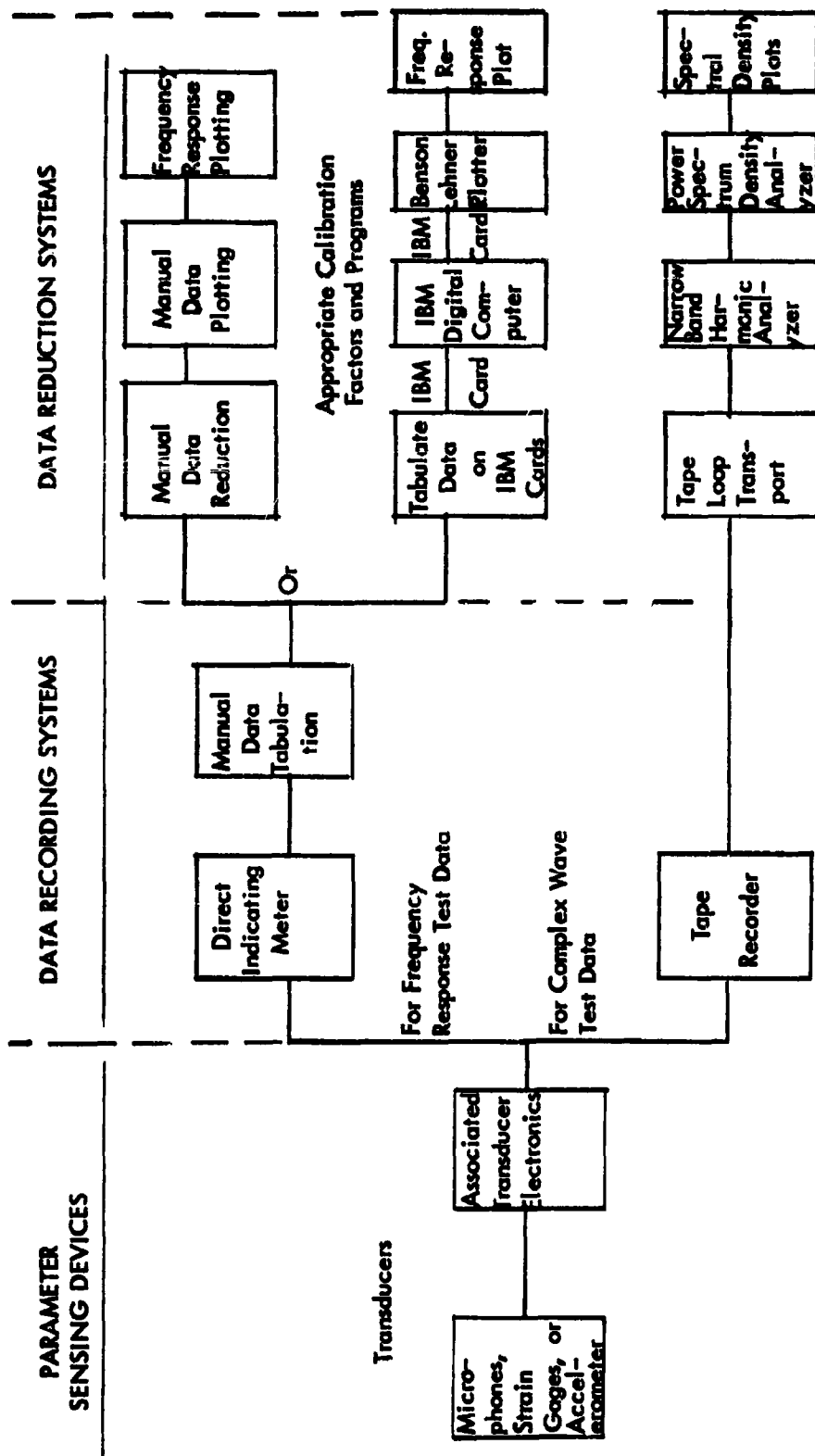
TYPICAL PANEL TEST SET-UP

FIGURE III J-2

FUNCTION	MANUFACTURER AND MODEL	QUANTITY
Condenser Microphones	Altec - Lansing 21BR-150 Altec - Lansing 21BR-180 Altec - Lansing 21BR-200	2 2 2
Crystal Pressure Transducers	Endevco Model 2502-500	6
Strain Gages	Baldwin-Lima-Hamilton (All Types) Tatnall (All Types)	As Needed As Needed
Amplifiers for Strain-Gage Bridges	Consolidated Electrodynamic Corporation (All Models)	50 Channels
Recording Oscillograph	Consolidated Electrodynamic Corporation (All Models)	50 Channels
Tape Recorders	Ampex FR-100	14 Channels or more if needed
Filters	Krohn-Hite Model 330M	2
Random Noise Generator	General Radio Type 1390B	1
Continuous Spectrum Analyzers (Narrow Band)	Davies Automatic Wave Analyzer, including tape transport, variable bandwidth filters, variable analysis rate, and inked chart recorder Panoramic Radio Co. Analyzer, consisting of: Model LF-2a Sub-sonic Spectrum Analyzer with inked chart recorder. Model LP-1a-CZM Sonic Spectrum Analyzer with auxiliary function - unit "C" Model PDA-1 Spectral Density Analyzer Model G-2 Sonic Response Indicator	1 set 1 set

McDONNELL INSTRUMENTATION AND DATA FACILITIES AVAILABLE FOR ACOUSTIC FATIGUE TESTING

TABLE III J-1



DATA SYSTEM BLOCK DIAGRAM

McDONNELL, ST. LOUIS

FIGURE III J-3

is being given to supplementing the existing condenser microphones with expanded dynamic range crystal microphones to permit measurement of a greater range of sound pressure levels.

Narrow band analyzers are used in conjunction with tape recorders for data analysis. The signal to be analyzed is recorded on tape and a loop is cut for use with the narrow band analyzers.

To measure the response of structures, strain gages are used. Investigations are presently being conducted to obtain a non-contacting type of resonant detector which would be easier and less expensive to use than strain gages.

5. INTERPRETATION OF DATA

The main purposes of the test programs at McDonnell are (a) to evaluate materials (b) to evaluate fasteners, and (c) to evaluate designs or manufacturing techniques.

Accelerated tests have been attempted using discrete frequency excitation but the results were unsatisfactory.

The factors used to describe a test are the time to failure, the frequency at which failure occurs, and the load input or stress level.

In the past, McDonnell developed a method of analysis for structural fatigue under high intensity noise loadings. Although it is not being used at present, it is described below.

The procedure that has been developed to predict the fatigue life of a panel is based on Miles' analysis of the response of a single-degree-of-freedom system to a random noise.

As in Miles' work, the response of a panel is described in terms of a randomly modulated carrier whose envelope is distributed with a Rayleigh probability density. The carrier frequency corresponds to the first resonance of the test panel.

Since the probability distribution of stresses is the same for each test, the index of severity of an individual test is the rms stress - the most probable

stress. Using the rms stress as the index of stress intensity it is then possible to develop an 'S-N' curve for random loading. This is done as follows.

If a test panel has a fatigue life of N cycles of the carrier, then the number n_i of those cycles lying in a narrow stress range can be taken as $P_i N$ where P_i is the probability that a stress lies in that range - given by the Rayleigh density function. Taking the mean stress of this narrow range and referring to an orthodox S-N curve, the number N_i of cycles to cause failure at this stress level is found. Assuming Miner's rule of linear accumulation of damage, the incremental damage (or the fraction of fatigue life 'used up') at this stress level is $\frac{n_i}{N_i}$ which is $\frac{P_i N}{N_i}$, thus the total damage is the integral over the whole stress range (0 to ∞) of this quantity and is equal to unity. This gives a relation between the random fatigue life N and the orthodox S-N data in terms of the Rayleigh density function.

As already stated, this relation is in terms of an integral which contains two stress dependent quantities; to accomplish this integration, Miles assumed that stress and cycles-to-failure in the constant-stress-amplitude fatigue test are related by a simple power law. In the method developed by McDonnell, the integration is carried out numerically using experimental S-N data.

The use of this random S-N curve can be described as follows:

Using curves of the sound field around a J-57 engine operating at a jet velocity of 1850 ft./sec., the sound level at the location of the panel is estimated. This first estimate is corrected to the expected operating condition of the service engine by using the fact that the sound level varies as the n th power of the velocity - empirical values of the exponent n are used. This corrected value is then increased by 4.5 db to allow for effects due to ground reflection. If there is more than one engine, this process is repeated to find the total of contributions to the sound pressure on the panel. This, of course, is the overall sound pressure and it is now required to find the power spectral density of this excitation in the frequency band corresponding to resonance in the structure. It is found that the power spectrum of a jet engine has a reasonably constant

shape when plotted as a graph of sound pressure level versus Strouhal number, the latter being defined as $(\text{frequency} \times \text{jet diameter})/(\text{bulk velocity})$. Using this fact, and calculating panel frequency by means of a nomograph, the spectral density in the resonance band is found. This quantity, together with the panel frequency, is introduced into a formula derived by Miles which gives the rms stress response. With the rms stress known, the random S-N curve can now be used to find cycles-to-failure — hence hours of life.

In a comparison of calculated and measured lives of a series of 17 panels it was found that 90% of the measured values lay in the range between half and double the calculated values.

6. TIME AND COSTS

Approximate rates for performing tests are:

\$10.00/man hour	-	Engineering Labor (Engineers and Technicians)
\$ 8.60/man hour	-	Laboratory Mechanic
\$ 6.00/man hour	-	Use of facility

We estimate that a test on a not too complex panel could be run for about \$500.00. The total cost of the facility is not available nor is the cost of individual specimens.

7. COMBINED ENVIRONMENT TESTING

No sonic fatigue testing in combination with other environments has been performed at McDonnell.

8. BIBLIOGRAPHY OF RELATED REPORTS

JOHNSTON, G. S. - Report 385, "Skin Cracking Due to Engine Noise", (1957)

Abstract

The report consists of a discussion of the theory and presentation of a method of analysis for structure subjected to jet engine noise. A sonic fatigue analysis is given for conventional skin stiffener construction of 204-T3, 7075-T6 including means of estimating engine noise and panel damping. Partial analysis is given for other material and skins with lands, but further test results are required to complete the analysis for these cases.

OLSON, JOHN - Report 45-49, "External Shingle Noise Test", Contract NAS 5-59, August 1959

Abstract

An external shingle was installed on a simulated capsule structure (Project Mercury) and subjected to an estimated acoustic environment. No failure occurred in this environment and the structure was therefore considered adequate.

III-K. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LANGLEY RESEARCH CENTER

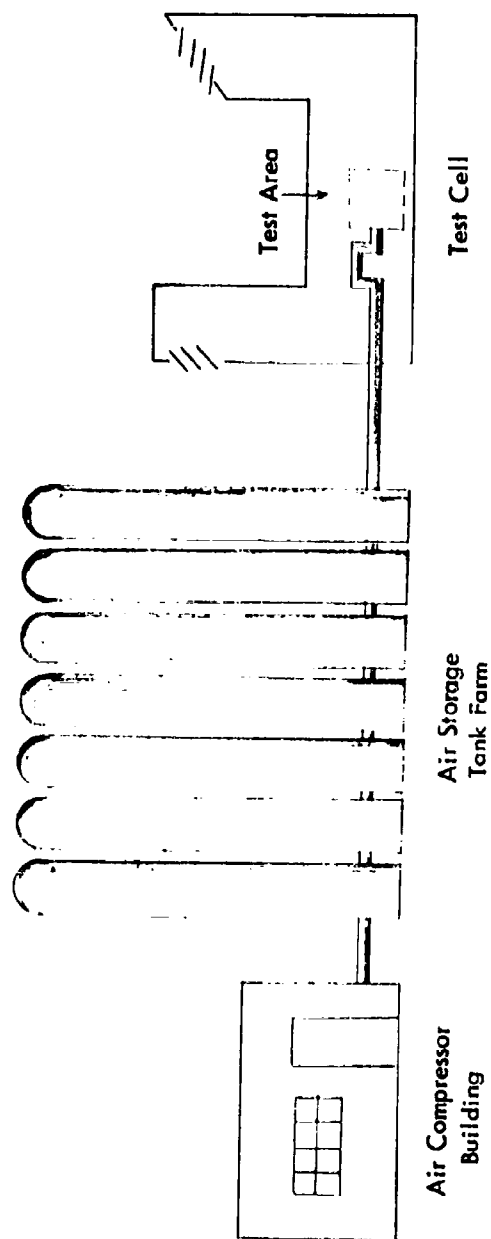
1. GENERAL DESCRIPTION

Langley Field has been remodeling their sonic fatigue facilities and the task is not yet completed. The major modifications will include the design and development of a new siren facility and the relocation of their air jet facility. Most of the sonic fatigue work at Langley has been done with their air jet facility. They have done work with a discrete frequency siren, but the siren is no longer in use and is not discussed in this report. Also no information regarding the new siren facility was available at the time of writing this report (January 1961). NASA, Langley has also performed some tests with a turbojet on the flight line.

The equipment for the air jet facility consists of four air compressors (18,500 horsepower), a 135,000 cubic foot tank farm for storing air up to 600 psi, and a hard wall test cell. * Air is throttled into the test cell through a pipe (12" diameter) with four 90° bends as is shown in Figure III K-1. The jet exhaust stream passes through the cell and out through an exhaust stack. The test area is located just downstream of the jet exit and around the periphery of the jet exhaust. Modifications of this facility will include a propane gas heater capable of raising the jet exhaust temperature to about 2500° F. in order to increase the obtainable noise levels.

* The compression and storage facilities also serve as an air supply for several wind tunnels.

NASA, LANGLEY



AIR JET NOISE FACILITY

FIGURE III K-1

2. TYPES OF SOUND SOURCES

Air Jet

Like a jet engine or a rocket engine the air jet is a continuous spectrum device. In this facility, four 90° bends are located up-stream of the exit in order to shape the noise spectrum and to obtain greater efficiency in the production of high intensity noise.

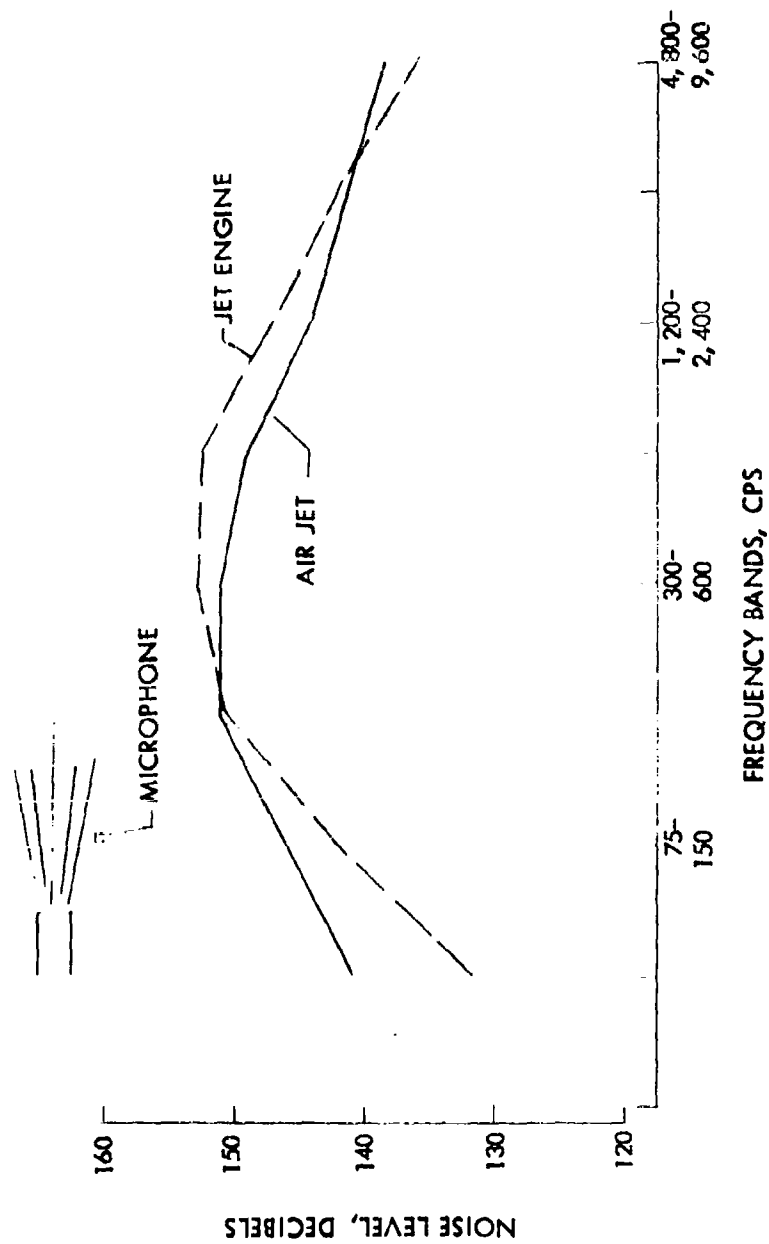
The noise environment shown in Figure III K-2 is typical of the spectra obtained with the air jet generator. This figure also includes a spectrum obtained at a similar location in the noise field of a jet engine of 10,000 pounds thrust. Both spectra were measured just outside the exhaust stream at a downstream distance of about two diameters. As can be seen, the overall noise levels are about 157 db, and the spectra are very similar in the frequency range from 150 cps to 1200 cps.

Measurements as to how the air jet noise is correlated in space and time have not been made, although such measurements are planned for the modified facilities.

Figure III K-3 shows the effects of jet pressure on the noise generated. The sound pressure was measured at a point below the jet exhaust stream, 1-1/2 jet exit diameters out from the jet center, and 2-1/2 jet exit diameters downstream of the exit (a typical place to locate a specimen). Spectra for three pressures (10, 26, and 50 psig) are shown. Overall sound pressures were increased from 140 db to 159 db as the pressure increased from 10 to 50 psi. One effect of increasing the pressure is to shift the spectrum peak in the high frequency direction.

To estimate the noise levels that might be obtained in the remodeled facility, tests were performed with 2" diameter jets at various air temperatures and the results were extrapolated to the large 12" diameter jet. Figure III K-4 shows the noise estimates for the 12" jet for various configurations and temperatures — a straight pipe with air at 530° R, four 90° bends with air at 530° R, and four 90° bends with air at 1460° R. NASA expects to obtain overall noise levels of the order of 170 db

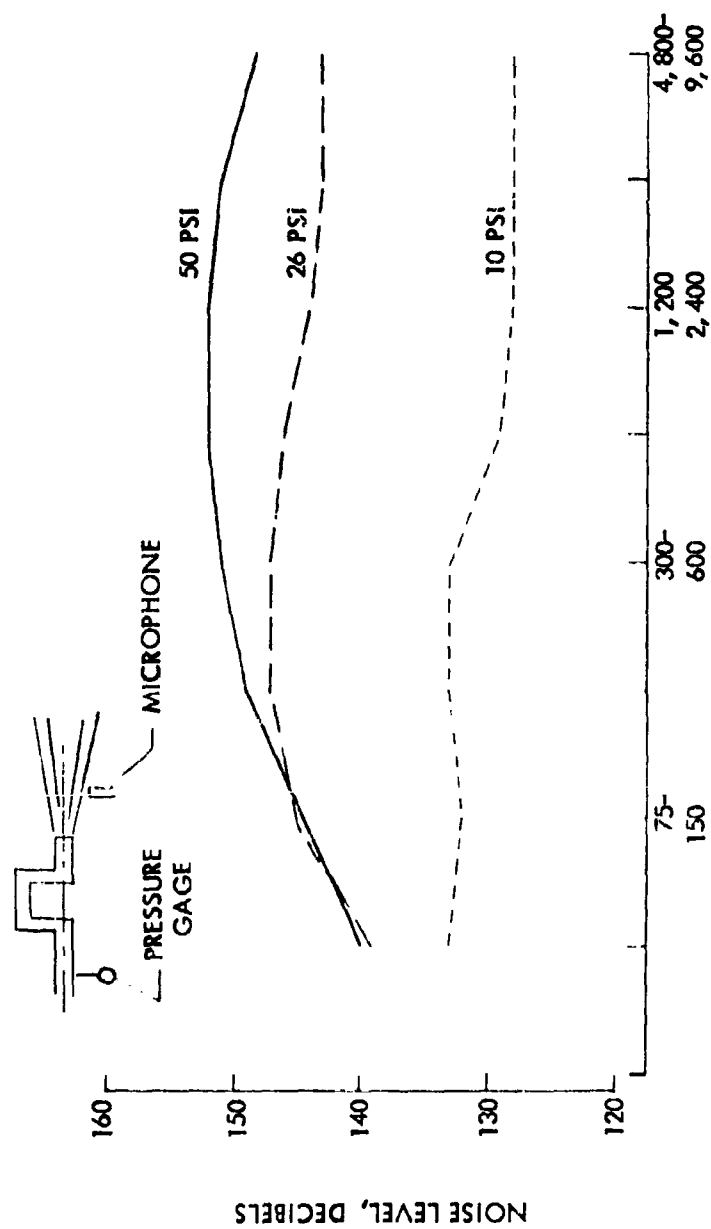
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COMPARISON OF NOISE SPECTRA FOR AIR JET FACILITY AND FOR A JET ENGINE

FIGURE III K-2

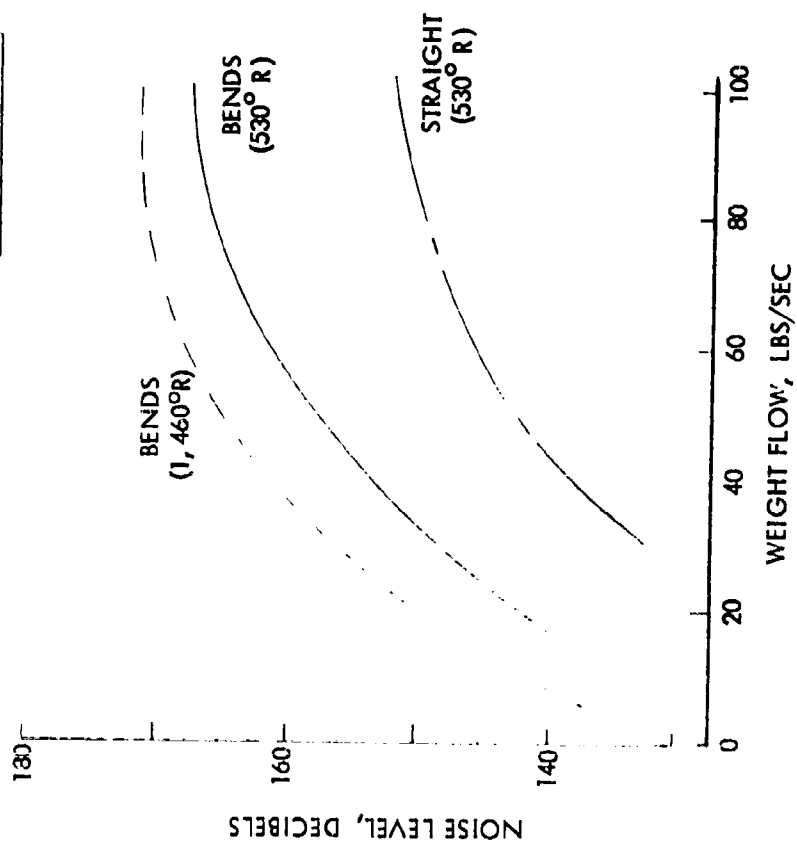
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EFFECTS OF JET PRESSURE

FIGURE III K-3

NASA, LANGLEY



ESTIMATED NOISE LEVELS FOR 12" AIR JET

FIGURE III K-4

in the remodeled air jet facility.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

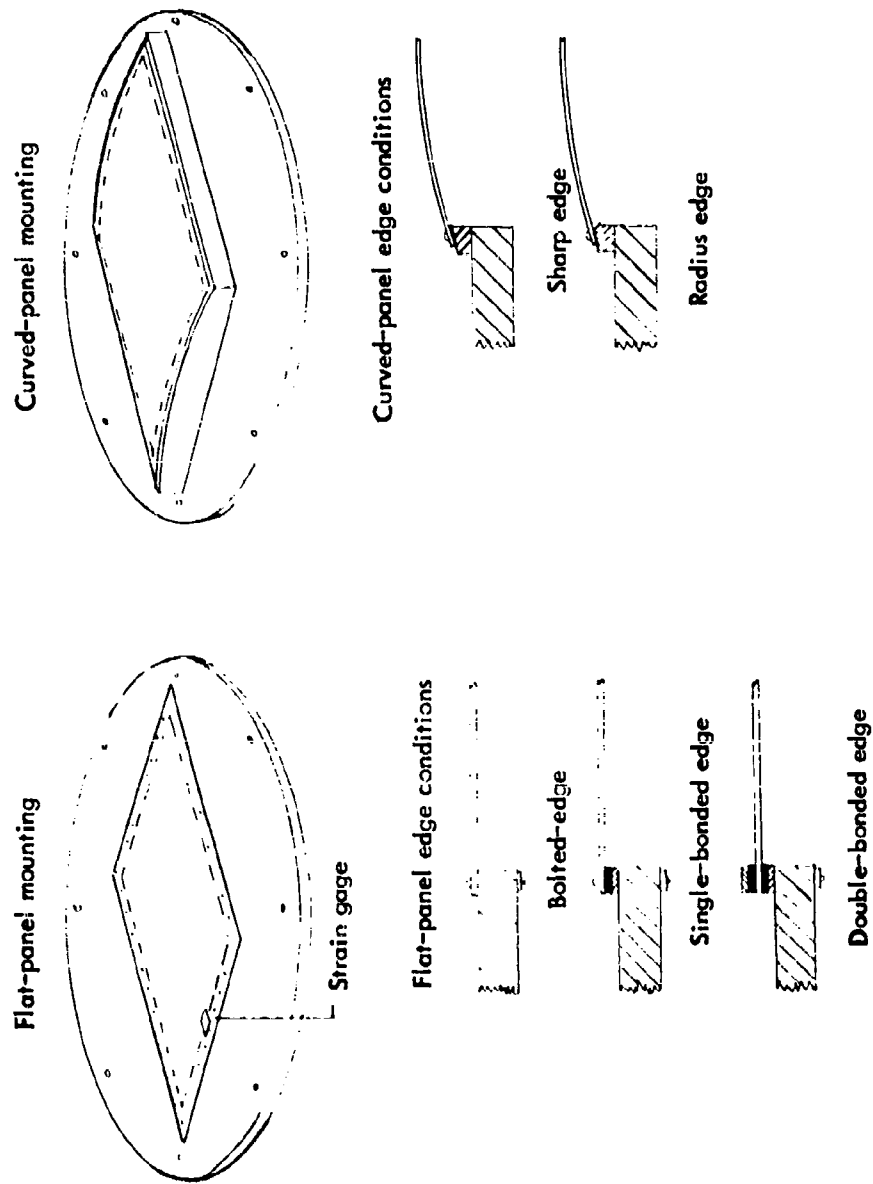
The models or test specimens, several of which may be tested simultaneously, are mounted on brackets extending out from a backstop. Only small specimens can be tested in this way and the usual practice is to use small sections of full scale structures and attempt roughly to duplicate the boundary conditions that would exist in the complete structure. Specimens of approximately 10 sq. ft. surface area are planned in the remodeled facility.

Specimens that have been tested with the air jet include flat and curved aluminum sheets, samples of heat shielded structures proposed for application in re-entry vehicles, structural panels of conventional aircraft, sandwich panels (honeycomb panels of bonded aluminum), large equipment components, and printed circuit boards. Figure III K-5 is a schematic diagram of the mounting configurations of curved and flat aluminum panels.

4. INSTRUMENTATION AND DATA ACQUISITION

(a) Noise Measurements

The noise measurement system consists of crystal microphones, tape recorders, frequency analyzers, and sound level recorders; and a system consisting of a dynamic pressure gage, an amplifier, and a panoramic analyzer. In one instance a pressure correlation study was made of the fluctuating pressure at eight points along the center line of each panel station. Only a rough measure of correlation was obtained. A more complete description of the method that was used for making correlation measurements is given in the report NASA TND-1. Special devices are being developed for more accurate measurement of space and time correlations of the sound pressures for use in the modified facility, but information on these devices was not available in time for this report.



(b) Specimen Response Measurements

The system used for stress response measurements in the past consists of strain gages, a 0-500 cps strain gage bridge, a recording oscillograph (0-150 cps), a 2,000 cps low-pass filter, and a thermocouple meter. Additional instrumentation for the measurement of strains, accelerations, deflection, damping, and temperatures is to be obtained for the remodeled facility but lists of instruments or block diagrams are not presently available.

5. INTERPRETATION OF DATA

The main purposes of the sonic fatigue facilities at NASA are to carry out research, to evaluate new designs of aircraft and missile structures and to develop methods and techniques of noise field measurements and structural response measurements. Occasionally, NASA will perform tests for government and industry. Accelerated testing has not been carried on at NASA. Automatic data processing systems are not used since the measurement systems do not require them. Test results are summarized by curves of fatigue life versus stress level at an arbitrary point, and fatigue life versus sound pressure level (SPL) at an arbitrary point (in the plane of the panel being tested). No spatial or time correlation of the pressure distribution is given. Curves representative of the acoustic fatigue data gathered at NASA are given in NASA TND-1. Some of these results are from a discrete frequency siren that is no longer in use.

An attempt has been made to compare data taken in an acoustic fatigue facility with that taken in a conventional fatigue test. Unfortunately, insufficient information was available to draw any definite conclusions. The results of this comparison are reported in Noise Control, Vol. 5, September 1959. This article also discusses very briefly an attempt to develop a figure of merit for the fatigue life of a panel by consideration of the total energy absorbed by the panel from the acoustic field.

It should be noted that Langley Field has recently built a large data

reduction center. It is expected that the experimental information gained from the new facilities will be processed in this center. This should permit more complete studies of correlation, frequency distributions, and amplitudes. Future programs will emphasize sonic fatigue research and one of the main objectives will be to compare the measured data obtained with the various fatigue life prediction theories now in use or which may be developed in the future.

6. TIME AND COSTS

The approximate cost of running tests using the air jet facility, including the personnel to run the facility, is \$200 to \$400 per hour depending on the temperature of operation. These costs do not include overhead.

The initial cost of the modification of their facilities will be approximately \$100,000 for instrumentation and \$200,000 for additions and modifications. No specific information is available on the costs of specimens since they vary considerably from test to test but a range of \$25 to \$500 would cover the various types of specimens they have used.

7. COMBINED ENVIRONMENT TESTING

Combined environmental tests have not been made with this facility. In the remodeled facility, provision will be made to supply power for making combined tests of temperature and sonic fatigue. At a later date, radiant heating will be provided that will allow specimen temperatures of approximately 2000° F.

8. BIBLIOGRAPHY OF RELATED REPORTS

HESS, ROBERT W., FRALICH, ROBERT W., and HUBBARD, HARVEY H., "Studies of Structural Failure Due to Acoustic Loading", NACA TN 4050, July 1957

Authors' Concluding Remarks (taken from report)

The problem of acoustic fatigue of aircraft structures has been discussed with particular emphasis on a comparison of the fatigue life due to discrete- and random-type loadings. In this regard it appears that both the stress level of the test and the type of model are significant; hence, no generalization can be made at this time. With regard to increasing the fatigue life, it was noted that increased stiffening of a panel due to curvature and pressure differential is particularly beneficial.

HESS, ROBERT W., LASSITER, LESLIE W., and HUBBARD, HARVEY H., "A Study of the Response of Panels to Random Acoustic Excitation", NACA RML55E13c, 1955

Authors' Concluding Remarks

Some preliminary measurements of the response of aircraft-skin panels to a random acoustic excitation have been presented and were found to be in general agreement with the results of an approximate analysis. These panels were noted to have very low damping and to vibrate mainly in their first modes in response to a random noise input. Root-mean-square stresses were noted to be proportional to the sound pressure per unit band width at the natural frequency of the panel and were higher for panels of less thickness.

LASSITER, LESLIE W., and HESS, ROBERT W., "Calculated and Measured Stresses in Simple Panels Subject to Intense Random Acoustic Loading including the Near Noise Field of a Turbojet Engine", NACA Report No. 1367, 1958

Authors' Concluding Remarks

An investigation was made of the stress response of simple flat and curved rectangular panels to random acoustic noise. In addition, this stress response was calculated by using general harmonic-analysis methods. This investigation indicated the following conclusions:

- a. At input pressures of the order of those encountered in full-scale configurations, the panels are somewhat non-linear. With flat panels this

non-linearity involves a stiffening spring constant; with curved panels the non-linearity involves a decreasing spring constant.

- b. Within reasonable limits in the stress range of the tests, the combined structural and radiation damping of flat panels is independent of panel thickness and depends only upon panel stress or deflection. Damping increases rapidly with stress at the higher stresses.
- c. The generalized harmonic analysis predicts stresses which are in fair agreement with measured values for flat panels and for curved panels of radius 4 feet over the range of input pressure tested.

REGIER, ARTHUR A., and HUBBARD, HARVEY H., "Response of Structures to High Intensity Noise", Noise Control, Vol. 5, No. 5, September 1959

Authors' Conclusions

It was noted that the most common damage to aircraft has involved the skin surfaces and that the damage may be correlated with the amount of energy absorbed by the structure. In order to minimize the damage due to noise, it is helpful to have: (1) a high impedance of the structure to reflect as much as possible of the incident energy, (2) high natural frequencies to radiate as much as possible of the energy accepted, and (3) a minimum of stress concentrations so that all the structure is used effectively.

The nature of panel failures can be reproduced quite successfully in the laboratory by various methods of testing. The problem of quantitatively predicting fatigue life from laboratory tests is much more difficult. Panel non-linearities are noted to be significant, particularly for short term fatigue life applications, and seem to act in a beneficial way.

EDGE, PHILIP M., Jr., "Random Noise Testing of Aircraft and Missile Components with the Aid of a Laboratory Air Jet", Presented at the 27th Shock and Vibration Symposium, February 25-27, 1959

Author's Concluding Remarks

An air jet facility for testing of large specimens in intense random noise environments has been described. Noise resistance tests of structural panels and equipment components have been successfully carried out in this facility at noise levels up to 161 db. The noise environment of the air jet closely simulated a jet engine and was easily controlled. These experiences and results from model tests indicate that the air jet offers promise as a laboratory

random noise generator for environmental testing at noise levels of at least 170 db.

HESS, ROBERT W., HERR, ROBERT W., and MAYES, WILLIAM H., "A Study of the Acoustic Fatigue Characteristics of Some Flat and Curved Aluminum Panels Exposed to Random and Discrete Noise", NASA TN D-1, August 1959

Authors' Concluding Remarks

The results of acoustic fatigue tests using random and discrete frequency loading on the simplified panels described herein indicate the following conclusions:

- a. Increases in time to failure were obtained as a result of increased panel thickness, increased panel curvature, and particularly for increased static pressure differential across curved panels.
- b. The structural failures produced were similar in nature for both the discrete-and-random-loading tests.
- c. At a given root-mean-square stress the times to failure were generally shorter for the random loading than for the discrete frequency loading. These differences in failure times were noted to be a function of stress level, the larger differences occurring at the lower stress levels.
- d. With regard to the role of discrete-frequency testing in these simplified structural designs, it follows that the location of weak points in the design can be satisfactorily accomplished but quantitative predictions of fatigue life are much more difficult.

III-L. NORTH AMERICAN AVIATION, INC.
COLUMBUS, OHIO

1. GENERAL DESCRIPTION

NAA has been carrying out tests on structural panels for the A3-J Vigilante, and the B-70 programs, and the methods of testing that are described have been used on these programs.

The Acoustic Laboratories at NAA, Columbus have four noise sources:

- (1) Electro-dynamic speakers
- (2) Cold Jet
- (3) High intensity discrete frequency siren
- (4) High intensity random siren

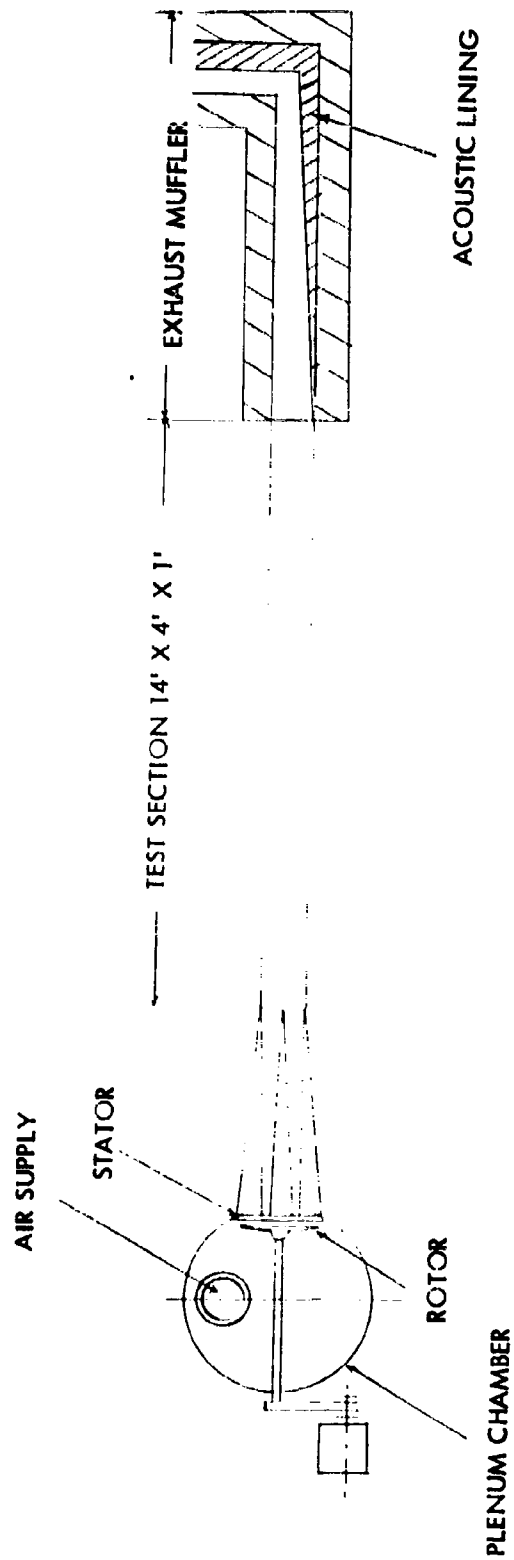
Of primary interest here are the discrete and random siren facilities that are used to test aircraft structure since the other two noise sources are of a rather low level (140 to 150 db) and are used mostly for electronic component testing.

A schematic diagram of the discrete frequency siren facility is shown in Figure III L-1 and a photograph of the set-up is shown in Figure III L-2. Each siren test set-up in the facility has the following major components: sirens with the associated drive systems, plenum chamber, horn section, test section, exhaust muffler and stack, and air supply system. The facility is located in a large Quonset hut that is lined with a 12" layer of 10.5 lb/ft.³ fiber glass to absorb noise, and the discrete frequency and random siren test set-ups share the same air supply system (80 psi at flow rates up to 550 lbs per minute).

(a) Discrete Siren

In the case of the discrete frequency siren, the air supply is aspirated to 1100 lbs per minute at two to three psi and delivered to a spherical plenum chamber. The air flows from the chamber to a horn section and is directed through the 12 stator

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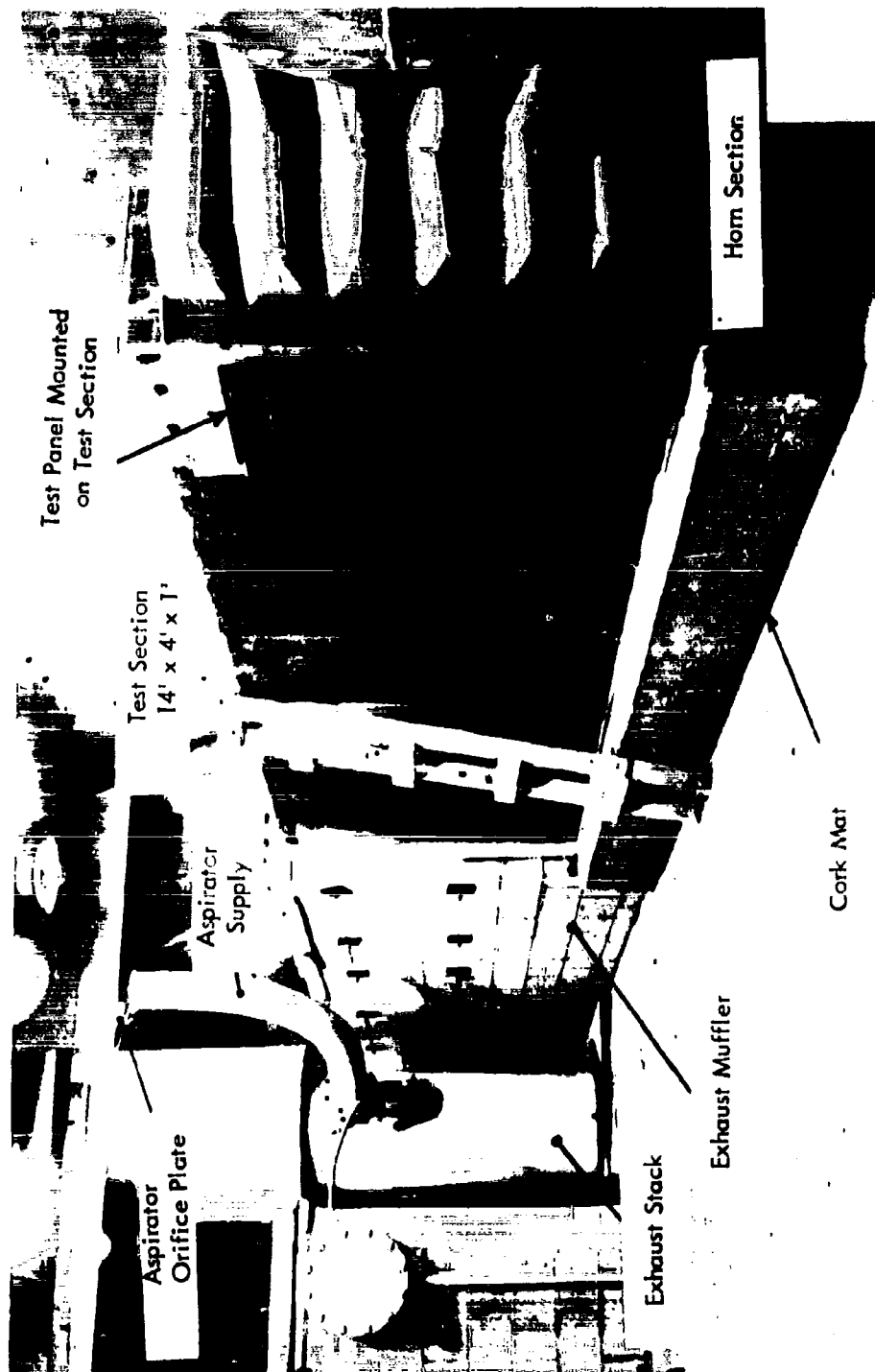


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GENERAL ARRANGEMENT OF NAA HIGH INTENSITY SIREN FACILITY

FIGURE III L-1

NAA, COLUMBUS



GENERAL VIEW OF SIREN FACILITY

FIGURE III L-2

ports of the siren. The sound and air then pass through a progressive wave test section, a muffler, and an exhaust stack.

(b) Broad Band Siren

A broad band siren of the VonGierke design and marketed by P. A. M. Associates, Inc. has only recently been installed and a detailed layout is not available. This siren consists of a Mach 1 nozzle and 4 overlapping rotors with randomly spaced teeth passing in front of the nozzle. The rotors pass in opposite directions with non-commensurate peripheral speeds so as to interrupt the air stream aperiodically. Each rotor is capable of cutting off the air stream independently from the others. The sound and air from this siren then pass through a horn that is mated to a test section identical to that of the discrete frequency siren.

2. TYPES OF SOUND SOURCES

Detailed performance measurements have been made of the discrete frequency siren and preliminary measurements have been made of the characteristics of the broad band siren.

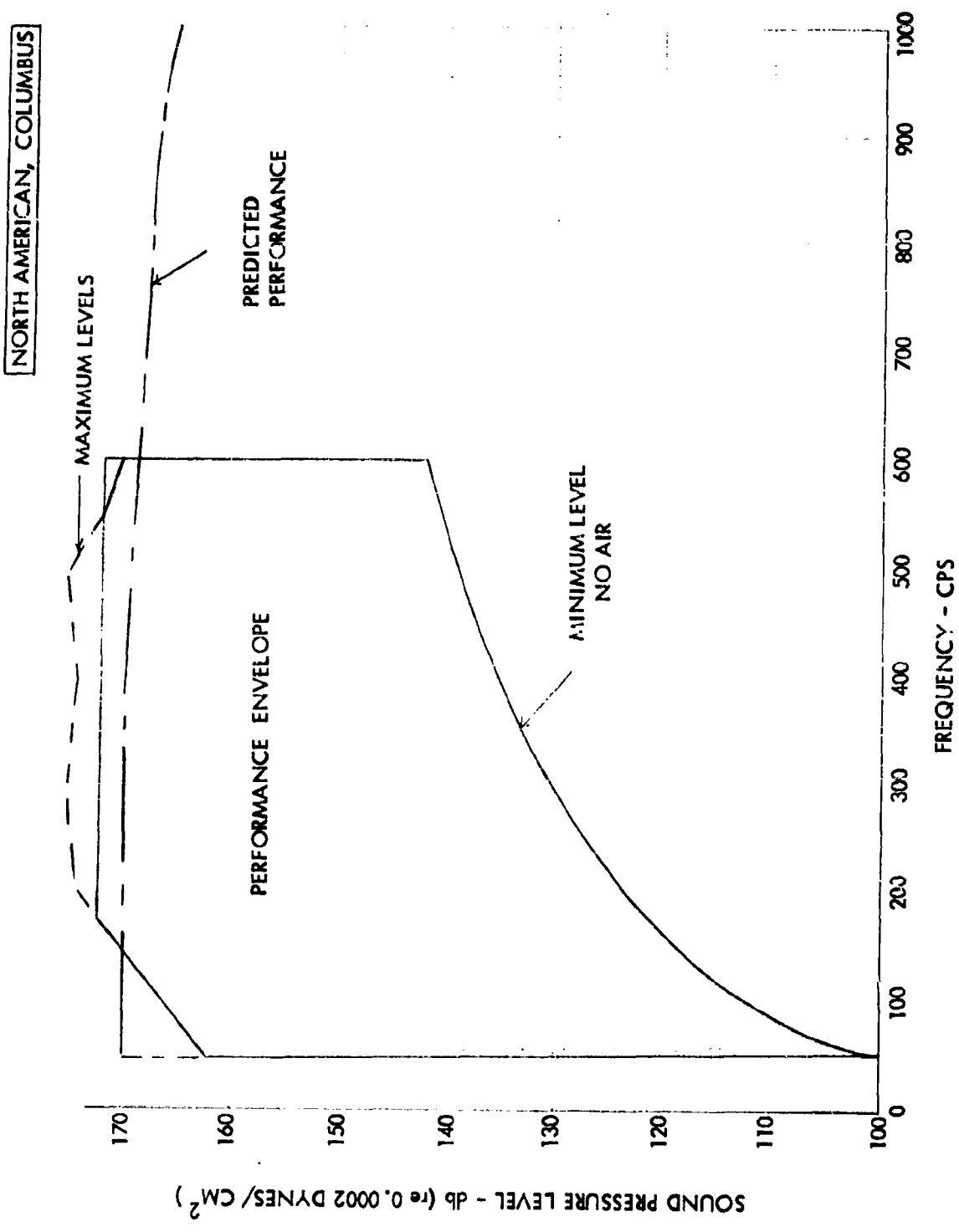
(a) Discrete Frequency Siren

Figure III L-3 is a photograph showing the stator plate and rotor assembly. The 12 port siren is operated by a variable speed motor and the frequency range of the device is 50 to 1000 cps. Figure III L-4 shows the performance envelope as a function of frequency including a curve of predicted performance. The facility is presently capable of generating sound pressure levels up to 175 db over a frequency range of 200 to 500 cps and 165 db from 50 to 550 cps. The variations in sound pressure level along the test section for frequencies of 100, 200, 300, 400, and 500 cps is shown in Figure III L-5. All of the measurements were made with microphones located along the center line of the test section. SPL variations in the vertical direction were measured and are reported to be within \pm one-half db. A representative plot of harmonic content at 160 db and 170 db for frequencies of 300 cps and 500 cps is given in Figure III L-6. In



STATOR PLATE AND ROTOR ASSEMBLY

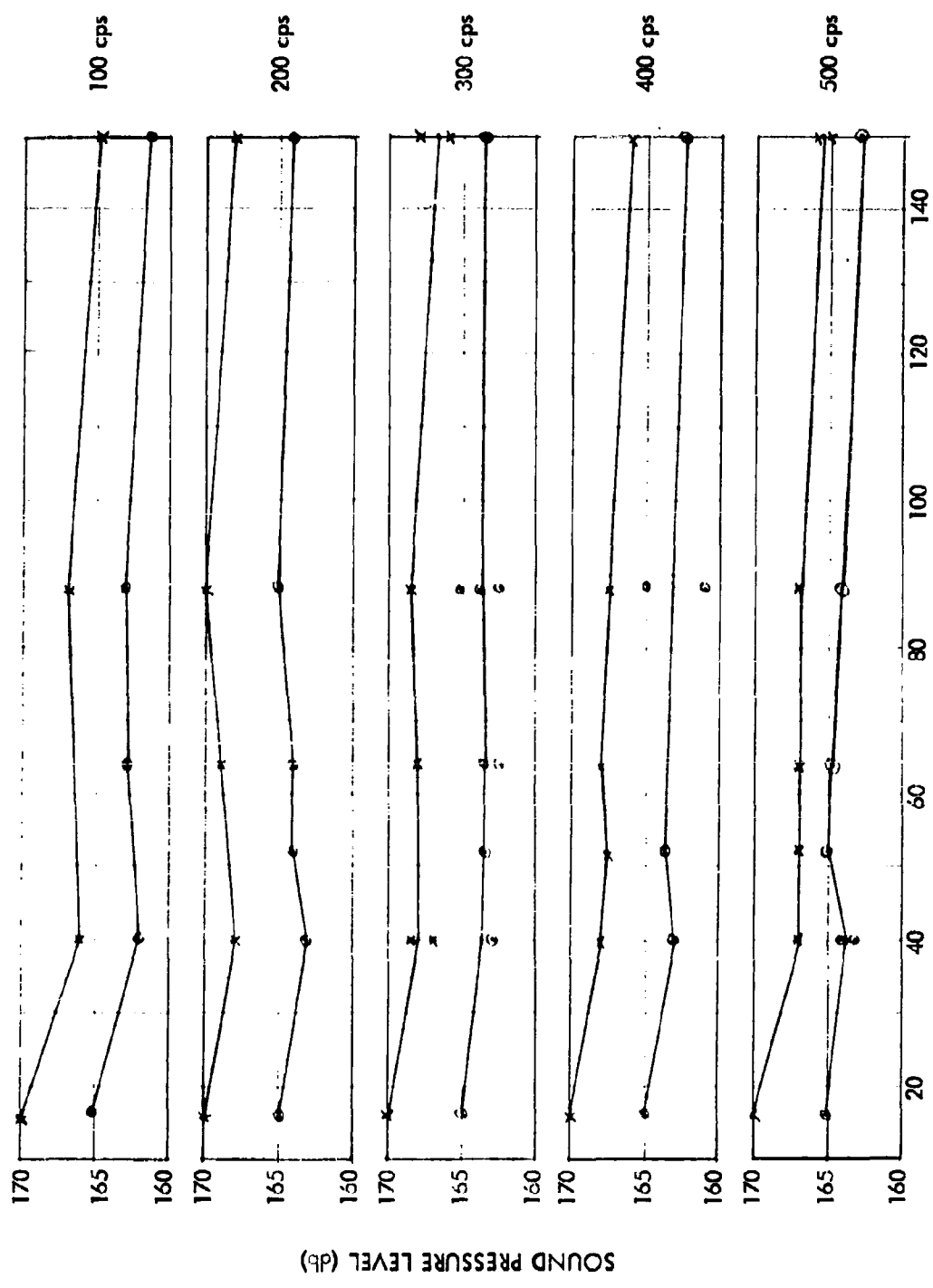
FIGURE III L-3



PERFORMANCE ENVELOPE AT UPSTREAM END OF TEST SECTION

FIGURE III L-4

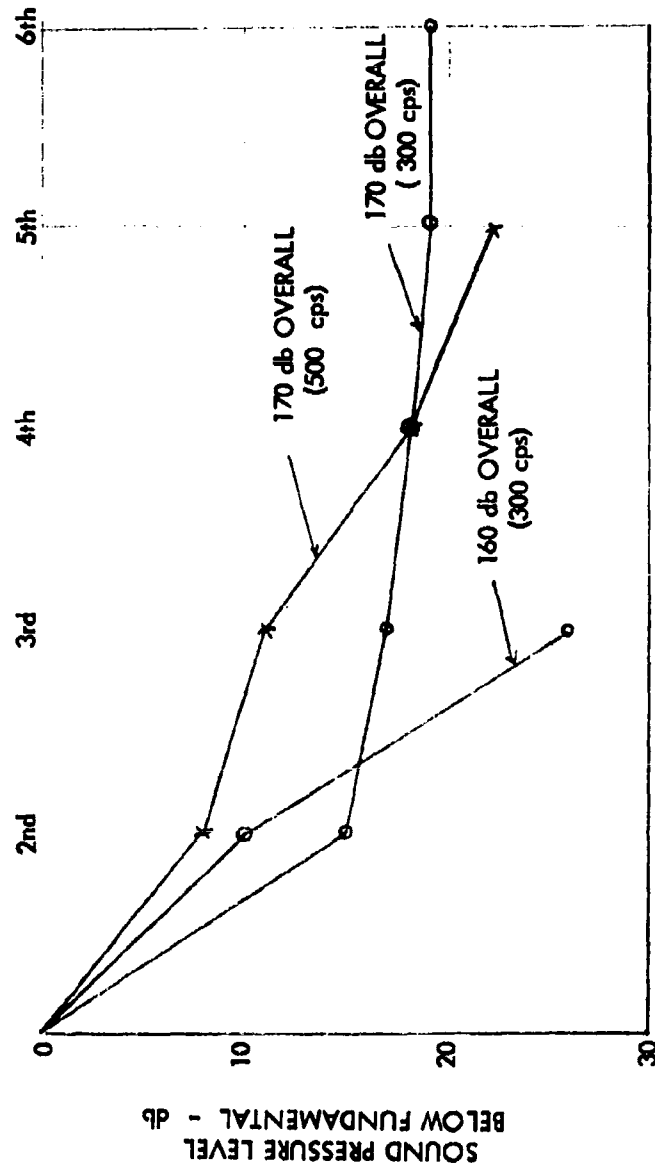
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DISTANCE ALONG TEST SECTION
VARIATION OF SOUND PRESSURE LEVEL ALONG TEST SECTION

FIGURE III L-5

NORTH AMERICAN, COLUMBUS



HARMONIC CONTENT

FIGURE III L-6

addition, some typical wave forms are illustrated in Figure III L-7.

(b) Broad Band Siren

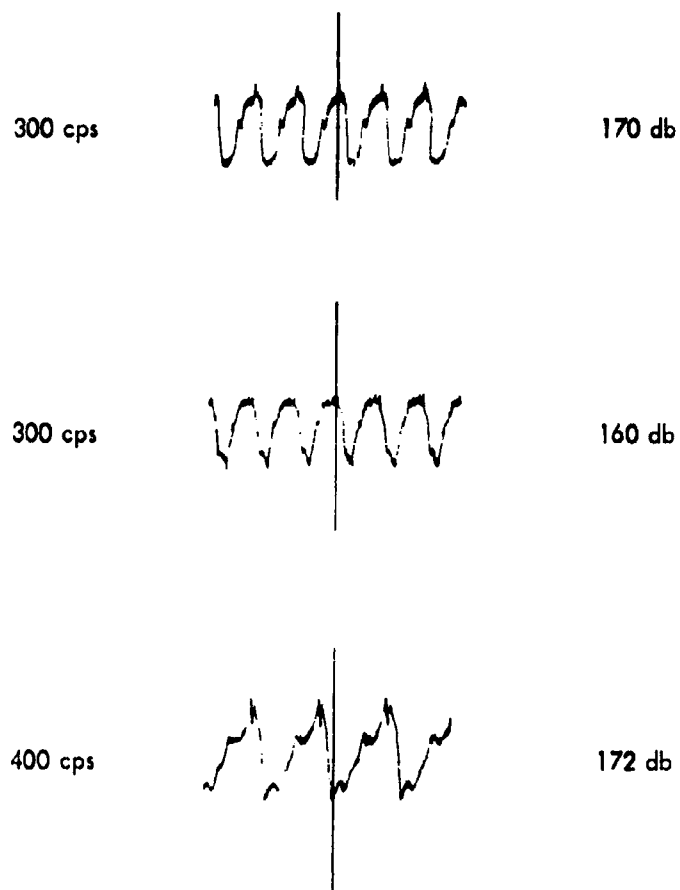
Measurements on the broad band siren show that over the frequency range 37.5-16,000 cps, the installation generates a power level of 173.5 db (re 10^{-13} watts) and a sound pressure level of 168 db (re 0.0002 dynes per square centimeter) with instantaneous peaks in excess of 3 to 1. The spectrum shaping capabilities of this siren appears at this time to be restricted or limited to hardware changes. A similar device that was developed at the Aero-medical Laboratory of the Wright Air Development Division is briefly discussed in Section III P. Figure III P-5 gives a third octave band analysis of this siren with and without a horn. Figure III P-6 shows the peak pressure distribution with this siren in a free field and the pressure distribution of a free field Jato Rocket.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

The general methods of siren testing for the discrete frequency siren are given below. Methods for use with the random siren have not yet been developed.

For discrete frequency tests, the siren is tuned to excite the most prominent resonant mode of the specimen. The response to the panel is indicated by strain gages placed in positions judged likely to be the most highly stressed. The sound pressure level to which the specimen is subjected is monitored with a microphone extended from the opposite side of the chamber and located close to the center of the panel. Primary tests are conducted to find the resonant frequencies and to determine the linearity of the panel response. To determine the resonant frequencies, the tests are performed by holding the pressure constant at a level 20 to 25 db below the expected test level and sweeping through a range of frequencies (usually from 50 cps to between 300 and 500 cps). A check on non-linearity is made by approaching the test level in the resonant mode in steps and recording strain gage readings. The resonant mode in the case of a non-linear panel is then determined by sweeping the frequency through a narrow band

SIREN WAVE FORMS
(Leonard and Rudnick Design)



SIREN WAVE FORMS

FIGURE III L-7

at the test sound pressure level. In the actual testing of the panel, the output of a selected strain gage is displayed on a meter and the rotor speed is adjusted to obtain the frequency at which the amplitude is a maximum. If any significant change in the gage output is noted (frequency or amplitude) the specimen is examined for damage. When the test period is several hours, testing is interrupted at half-hour intervals to examine the specimen.

The random and discrete frequency siren test sections are identical. Although a large test area, 14' x 4' is available for testing panels at grazing incidence, comparatively small specimens (2' x 1') are generally used. A typical specimen being prepared for a test is shown in Figure III L-8. The panel forms a part of the wall of the plane wave tube. It is suggested by NAA, Columbus that such a technique represents the conditions for structure subjected to boundary layer turbulence or structure located behind the engines such as the rear fuselage, stabilizers and wing trailing edges. The side opposite the test area has provision for mounting microphones for sound pressure level readings and harmonic analysis.

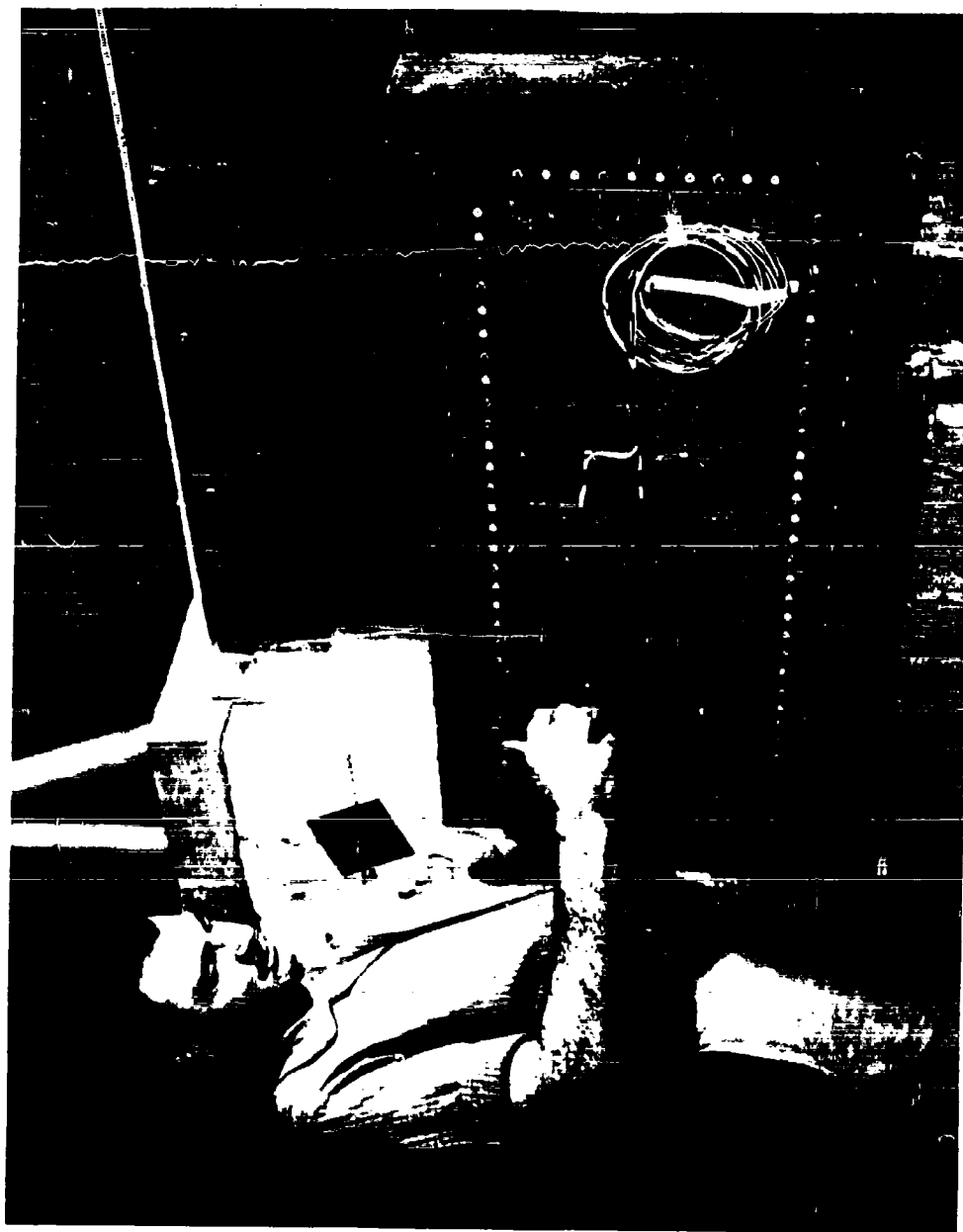
4. INSTRUMENTATION AND DATA ACQUISITION

During the performance of a sonic fatigue test all data pertinent to the test specimen and its environment are controlled and monitored through a control console and allied instrumentation.

The console is instrumented to monitor the following:

- Plant air supply pressure and temperature
- Aspirator air supply pressure and temperature
- Differential pressures
- Siren shaft vibration and temperature of shaft bearings
- Frequency of acoustic excitation
- Sound pressure level, 6 microphones
- RMS voltage of strain gages

A 50-channel Midwestern oscillographic direct reading recorder, strain gages and an X-Y plotter provide test specimen monitoring. Additional Dynamics



TYPICAL SPECIMEN IN PREPARATION

NAA, COLUMBUS

FIGURE III L-8

Laboratory equipment is available for mode shape analysis and the 7-channel Technical Products Corporation analyzer is available for discrete and narrow band analysis to ascertain the harmonic content of test section noise.

Equipment available for measurement of noise levels include Altec Lansing microphones, a General Radio and a Scott portable sound level meter system with a non-directional microphone, amplifier and indicating meters, and a voice microphone for including correlation information along with data on a tape. Calibration equipment for use with microphones includes the Bruel and Kjaer type 4119 microphone calibrator and accessories, the General Radio type 1552-B sound level calibrator, and the Altec Lansing type 12185 acoustic calibrator. Two Western Electro 640AA microphones and a small anechoic chamber are also utilized for calibration purposes.

Noise is analyzed in overall levels, octave bands, $1/3$ octave bands, or by discrete frequency analysis through 20 kc. Data may be read directly from meters, recorded by X-Y plotters or recorded on paper tape in discrete frequency or band levels. Analysis equipment includes the General Radio type 1550A octave band analyzer, the General Radio type 760-B continuous spectrum analyzer, a Panoramic Sonic and Subsonic analyzer LP-1, a Bruel and Kjaer $1/3$ octave band analyzer, and seven additional channels of Technical Products Corporation equipment that is similar in function to the Panoramic Sonic analyzer.

5. INTERPRETATION OF DATA

In the interpretation of data, various methods are used. The choice of the method is the prerogative of a project group or company for whom the tests are being performed. For tests performed on their own panels it is assumed that most of the fatigue damage will be caused by the least damped resonant modes of the panel. Test times of 10 to 20 hours are used. At the present time, both the methods developed by Getline (see Section III-E.) and by Belcher (see Section III-F.) for determining fatigue life have been used, and NAA is collecting service data that will be used to

compare the results of these methods with actual service life. They are also planning to compare the results of test panels placed in jet engine test cells with those placed in the siren facilities and to use the recently installed random siren for comparisons of the fatigue lives of specimens tested with this siren and with the discrete siren.

6. TIME AND COSTS

NAA estimates a cost of \$50.00 to \$100.00 per hour of testing. This would include labor, overhead, and power but not amortization costs. Specimens cost from \$100 to \$6000 each depending on their complexity, and from 1 to 6 specimens are prepared for a given panel configuration. The discrete siren facility cost \$58,000, including special instrumentation but not including the air supply. The cost of the random siren was approximately \$12,000, not including the test section and installation cost.

7. COMBINED ENVIRONMENT TESTING

NAA is currently working on a program in which a 600° F. heating environment will be required in addition to the high intensity noise environment. They are thinking of using radiant heating in combination with their sonic fatigue testing for this program but no detailed plans have been made. Plans are also being made to provide equipment for combined vibration and sonic fatigue tests by the addition of a 5000 lb random vibration shaker to their laboratory.

8. BIBLIOGRAPHY OF RELATED REPORTS

**NORTH AMERICAN AVIATION, INC., "Acoustic Capabilities", Brochure
NA60H-13 (24 May 1960)**

Abstract

This is a general brochure briefly describing the Columbus NAA acoustic facilities. These include (a) Electrodynamic Speakers (b) High Intensity Discrete Frequency Siren (c) Cold Jet and Reverberation Chamber.

**PROCEEDINGS OF THE INSTITUTE OF ENVIRONMENTAL SCIENCES, Program
on Acoustic Problems of Flight Vehicle Design - Sponsored by NAA-
December 9, 1959**

Abstract

The following pertinent papers were given by NAA personnel:

- (a) W. R. Laidlaw - "Environment Problems in Aeronautics".
- (b) V. L. Beals - "Acoustical Problems of Flight Vehicle Design".
- (c) W. G. Dunn - "State of the Theoretical Acoustic Art in Aeronautical Engineering".
- (d) G. D. McAdoo - "Noise Measurement in Flight Vehicle Design".
- (e) J. A. Hill - "Equipment Testing to Sonic Environments - Facilities and Techniques at NAA, Columbus".
- (f) B. J. Spice - "Sonic Fatigue Testing Facilities and Techniques at NAA, Columbus".
- (g) J. A. Hayes - "Development of the Cold Jet as a Noise Source".

**SPICE, B. J., "Performance Measurements of the Discrete Frequency Siren of the
North American Aviation Sonic Fatigue Facilities" - Dynamics Laboratory
Report No. 84 - 3 October 1960**

Summary

The high intensity discrete frequency siren facility of the NAA, Columbus sonic test facilities is described and performance data are presented.

The facility is presently capable of generating sound pressure levels up

to 175 db over a frequency range 200 to 500 cps, and 165 db from 50 cps to 550 cps. Specimens of panel configuration measuring up to 14' x 4' in size can be tested at grazing incidence.

III-M. NORTH AMERICAN AVIATION, INC.
LOS ANGELES, CALIFORNIA

1. GENERAL DESCRIPTION

At the present time, North American sub-contracts its sonic fatigue tests to facilities in other companies. The tests, however, are specified in detail by North American and sometimes even supervised by their personnel.

The facilities that are described are in the process of being built and, in many instances, detailed information is not available.

The new facility of NAA at Los Angeles was designed by Bolt Beranek and Newman, Inc. and has many of the features of the new WADD installation. Two sirens generate sound that passes down a progressive wave test section, through a catenoidal horn, and into a test chamber. The test chamber can be reverberant or, by placing pseudo-anechoic wedges opposite the horn it can be made partially anechoic. The wedges can be automatically raised or lowered across the wall of the termination room that faces the apex of the siren horn. Figure III M-1 is a cross-section of the entire facility, Figure III M-2 is an aerial view of the installation, and Figure III M-3 is a cross-section of the test chamber.

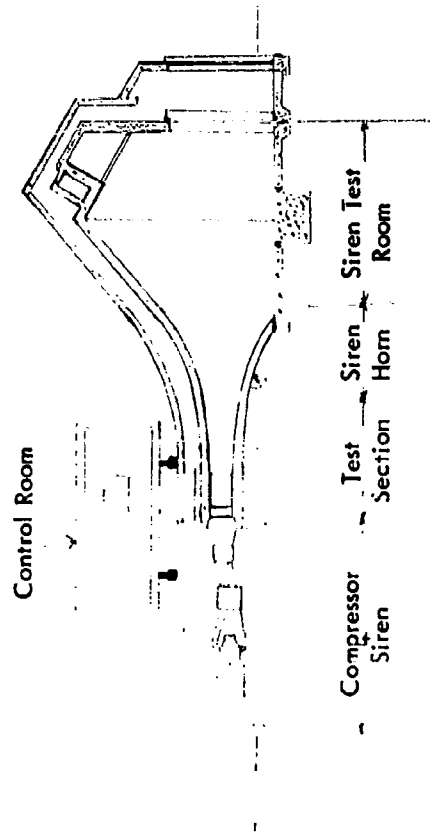
The air supply for the sirens delivers 9800 cubic feet per minute of air at 6 psig and at approximately 100° F. It is obtained from two Pratt and Whitney, R-4360 superchargers, driven by two 400 horsepower electric motors. Figure III M-4 gives some indication of the size of the facility.

2. TYPES OF SOUND SOURCES

The siren sound source for this facility is essentially the same as the one designed by BBN for Wright Air Development Division and has the following performance

NORTH AMERICAN, LOS ANGELES

HIGH INTENSITY SIREN FACILITY



ENTIRE FACILITY CROSS SECTION

ACOUSTIC LABORATORY

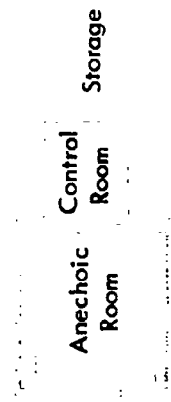


FIGURE III M-1

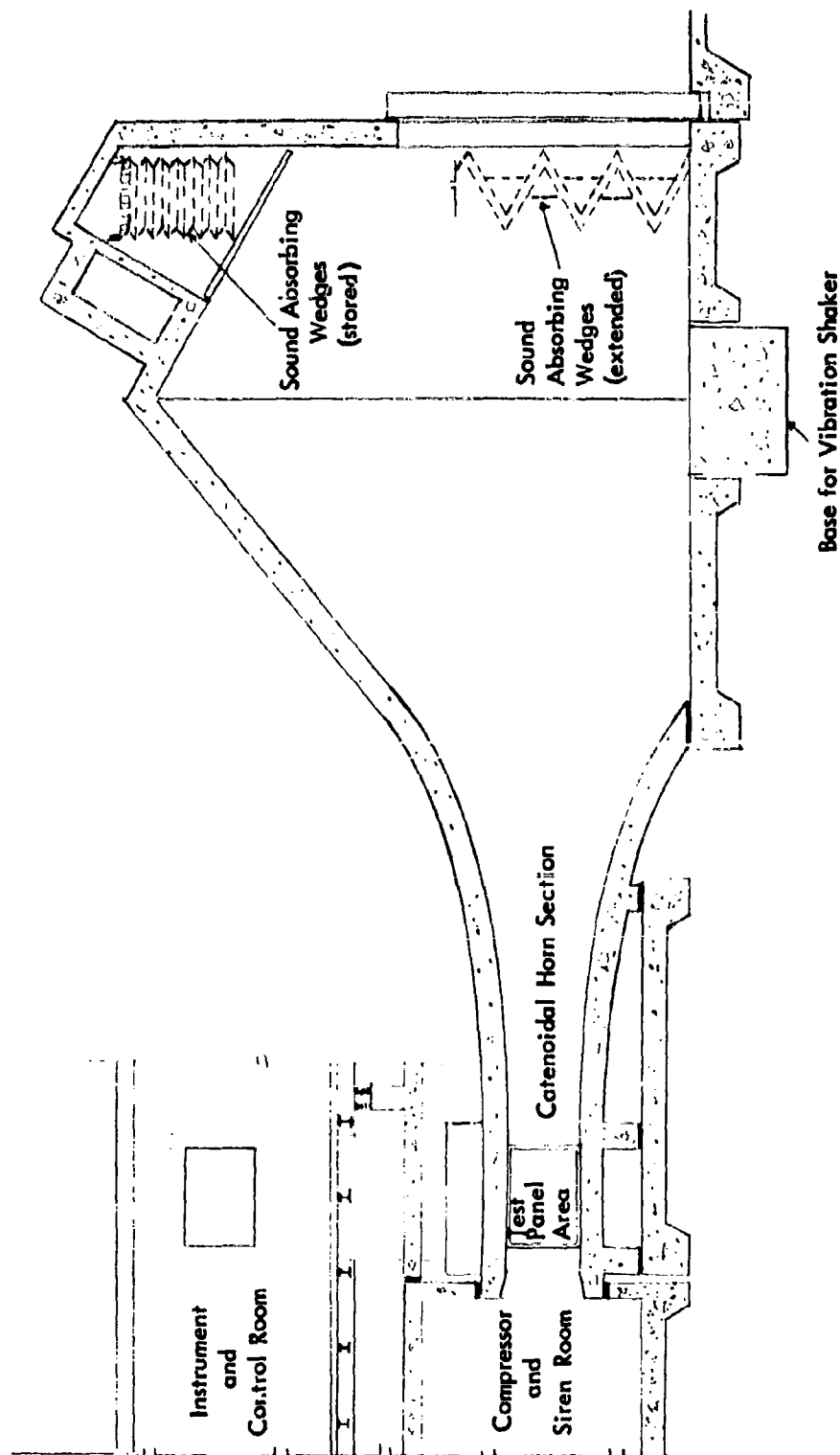
NORTH AMERICAN, LOS ANGELES



AERIAL VIEW OF HIGH INTENSITY NOISE FACILITY

FIGURE III M-2

NORTH AMERICAN, LOS ANGELES



TEST CHAMBER CROSS SECTION

FIGURE III M-3

NORTH AMERICAN, LOS ANGELES



SIDE VIEW OF HIGH INTENSITY' NOISE FACILITY

FIGURE III M-4

specifications.

(a) Frequency (Siren Speed Control)

The frequency (speed) range of 50-10,000 cps (66.7 to 13,333.3 rpm) will be generated by two choppers with frequency ranges of 50 to 2000 cps (66.7 to 2666.7 rpm) and 500 to 10,000 cps (666.7 to 13,333.3 rpm). Each chopper is to be driven by a separate hydraulic motor. A single hydraulic system (an electric motor driving a hydraulic pump) will be employed in the operation of the two hydraulic motors. Separate frequency (speed) controls will be provided to allow individual or simultaneous operation of the two choppers. The frequency will be continuously variable over the two ranges 50 to 2000 cps and 500 to 10,000 cps, with provisions for manual and automatic control of the frequency. A feedback signal from a NAA displacement transducer will provide the input for the required automatic control.

At frequencies in the range from 50 to 2000 cps the control accuracy is specified to be $\pm 0.25\%$ of the frequency setting ($\pm 0.33\%$ of the rpm setting) or ± 1 cps (± 1.33 rpm) whichever is greater. At frequencies in the range from 500 to 10,000 cps the control accuracy is specified to be $\pm 0.5\%$ of the frequency setting ($\pm 0.67\%$ of the rpm setting).

(b) Sound Output (Air Control System)

Acoustic Power - The dynamic range of the generator output will be 278.7 to 27,870 acoustic watts to give 150 db to 170 db (re 10^{-16} watts/cm²) sound pressure levels over an area of three (3) square feet. This dynamic range will be provided by an air control system which will allow the generator output to be continuously variable in steps not to exceed a 2 db power ratio. The generator will have a maximum output (27,870 acoustic watts) over the frequency range of 250 to 1500 cps (266.7 to 2000 rpm) and the acoustic power will not decrease more than 5 db at 50 cps and 15 db at 10,000 cps below the maximum level

The air control system is specified to allow the output level to be controlled to an accuracy of ± 2 db at a fixed frequency and a given acoustic power level

in the output range from 2,787 to 27,870 watts.

(c) Amplitude Modulation

The following provisions for amplitude modulation of the output will be provided:

Control of the peak-to-rms ratio from 3 db to 20 db. Amplitude modulation to be imposed on the fundamental tone of the generator with a frequency bandwidth variable from 0 to 50 cps.

An electro-hydraulic servo system complete with power amplifiers, pre-amplifiers, and hydraulic actuator adequate to control the modulation through the use of a modulator plate when supplied with an input signal of 0.1 to 1.0 volts. Input impedance of the system shall be at least 10,000 ohms.

(d) Predicted Termination Room Levels

According to BBN calculations the SPL in the reverberant termination room will be below that at the grazing incidence test section by approximately the following amounts:

50 cps	-	1 db down
200 cps	-	7 db down
500 cps	-	12.5 db down
1000 cps	-	17.5 db down
5000 cps	-	30 db down
10,000 cps	-	37 db down

3. TEST METHODS AND SPECIMEN ARRANGEMENT

In the past, test methods have been specified by NAA when they have had tests performed in other laboratories. The report "Acoustical Fatigue Test Program of F100, Fuselage, Wing and Empennage Structural Panels", Report No. NA591846 contains a good example of one of the methods that has been used and which is essentially the same as the techniques used at Douglas. In the above example the panels were tested at normal incidence. The testing was started at a relatively low sound pressure

level and run for 15 minutes at each of three dominant modes. The sound pressure level was then increased in steps of 3 decibels repeating the above procedure until failure of the specimen occurred or the maximum capacity of the test apparatus was reached.

From the specimens stress load curves plotted for each resonant mode and sound pressure level, the appropriate S-N curve for the material, and the accrued time in sound pressure level at which the specimen actually failed, an equivalent random noise sound pressure level for a desired service life was calculated in accordance with the procedures described for the Douglas facility. The specimens used in this program were taken from stock production parts. It is not known whether the same test methodology will be followed in the new facility or whether new procedures will be developed.

In the new facility, the maximum panel size in the grazing incidence test section is 3' x 5'; in the reverberation termination room 6' x 25'. Strain gages will be located by judgement after imposing a grid on the specimen and looking at it with a stroboscope while it is being excited in a low level sound field. Failure will be detected visually and there will be a pre-test inspection for flaws or cracks using X-ray, ultrasonic, and visual methods.

4. INSTRUMENTATION AND DATA ACQUISITION

The control and measurement room was not completed at the time of preparing this report and block diagrams of instrumentation are not available. The following, however, is a list of instruments that is planned for noise and response measurement and analysis.

- Oscillograph - 36 Channel and Amplifiers
- Temperature Control and Recorder
- Strain Gage Power Supplies
- Oscilloscope Dual Beam
- Vacuum Tube Voltmeters
- Microphones and Microphone Power Supplies (Altec BR Series)

Circuit Calibrators
Tape Recorders
Sound and Vibration Analyzers
Graphic Level Recorders
Panoramic Sonic Spectrum Analyzer
Closed TV Circuit - X-Y Recorders
Audio Oscillators

5. INTERPRETATION OF DATA

The sonic fatigue programs carried out by NAA have been performed either in the normal impingement facility at Boeing, Seattle, or the progressive wave facility at Convair, San Diego. The objectives of these programs were:

1. To establish acoustical fatigue limits for basic structural paneling.
2. To determine the allowable level of random noise on structures of flight vehicles under development.
3. To establish the acoustical fatigue life of structures in acoustically critical areas on operational flight vehicles.

A multi-mode-step-testing technique developed by Mr. P. M. Belcher of NAA, and Messrs. J. D. VanDyke and A. L. Eshleman, of Douglas Aircraft, is currently used by NAA for all acoustical fatigue test programs. This technique consists of consecutively exciting with a discrete frequency sound source, each of the dominant modes of the specimen for periods of 15 minutes (approximately 5×10^5 cycles). This process is initially performed at the lowest sound pressure level that provides significant specimen response and is continued in 3 db increments of increasing intensity until specimen failure occurs, or maximum capacity of the testing apparatus is reached. By assuming a cumulative damage rule and by knowing the flexural fatigue characteristics of the specimen material, a maximum random noise level can be calculated for any desired service life.

The methods for determining fatigue life are exactly the same as those outlined in Section III F-5 (Douglas, Santa Monica) and the reader is referred to

that section.

6. TIME AND COSTS

The total cost for the NAA, L. A. facility is estimated to be \$338,000.

A breakdown of this cost is as follows:

Structure	\$ 135,000.
Sound Generation System	120,000.
Motors + Compressors	32,000.
Instrumentation	51,000.

Actual testing cost has not yet been determined.

7. COMBINED ENVIRONMENT TESTING

It is anticipated that the new facilities will provide equipment for running combined environmental tests involving noise, vibration, and temperature. The vibration tests will be run on a shaker placed in the reverberant termination room of the facility. Combined tests are planned with temperatures of from 1200° F. (using radiant heat lamps) to - 100° F. (using CO₂). The heating and cooling would be provided on the back side of a specimen and it is expected that the use of an acoustical window, (thin sheet of metal in front of panel) will eliminate the heat transfer away from the specimen due to rushing air from the siren port.

8. BIBLIOGRAPHY OF RELATED REPORTS

HYDROMECHANICAL LABORATORY (prepared by) "Acoustical Fatigue Test Program of F-100 Fuselage, Wing and Empennage Structural Panels", NAA Report, NA59-1846, December 1959

Summary

This report discusses sonic fatigue tests that were performed on the F-100 airplane panels at the Boeing, Seattle, normal impingement siren facility. The report describes the specimens that were tested, the test conditions, the procedures used, and the method of data interpretation and results.

BOLT BERANEK AND NEWMAN, INC. (prepared by) "Preliminary Design of Acoustic Test Facility for North American Aviation", Report No. 575, October 1958

Summary

This report describes the philosophy behind the design, the functional requirements of the facility, and the operational capabilities of the facility; a description with drawings is included.

RADER, W. P., BELCHER, P. M., VANDYKE, J. D. and ESHLEMAN, A. L., Douglas Aircraft Company, "Load Computations used in Acoustic Fatigue Tests of DC-8 Structure", Report No. SM-23234, November 14, 1958

Abstract

This report provides a record of test load computations for fatigue tests and for assembly proof tests performed at the Sound and Vibration Laboratory of the Santa Monica Division on specimens of acoustically loaded DC-8 structural components. This is an abridged edition of the original report and contains a summary of the work performed with examples of the test method along with several typical structural panels that were tested.

1. GENERAL DESCRIPTION

Norair is still developing their acoustic test facilities. At the present time (Dec. 1960), they have completed a reverberant chamber to be used with their noise generator for electronic component testing and are in the process of developing a progressive wave chamber for structural testing. The information presented in this description is what has been made available from their prototype designs.

The facility consists of a Norair acoustic generator (air modulator) which can be connected to either a progressive wave chamber or a reverberant chamber. Figure III N-1 is a schematic of the Norair components connected to the progressive wave chamber, and Figure III N-2 is a photograph of the latest generator as it is used in conjunction with the reverberant chamber. Power inputs to the noise generator come from an air supply (1.5 lbs per second at 120 psig) and a 7 kilowatt audio amplifier. The facility as set up is for grazing incidence testing but the generator with a horn can be used for testing at normal incidence.

2. TYPES OF SOUND SOURCES

(a) Acoustic Generator

The generator is essentially an air stream modulator and produces sound energy by the modulation of high pressure air through a poppet valve mechanism. The lift of the poppet valve is controlled by an electromagnetic driver. The pressure of the air supply is such that highly non-linear effects due to strong shock waves are produced in the throat of the horn. As a consequence of this, and of the sudden opening and shutting of the poppet valve, the acoustical output resulting from a sinusoidal

NORTHROP

NORAIR
PROGRESSIVE WAVE ACOUSTIC CHAMBER

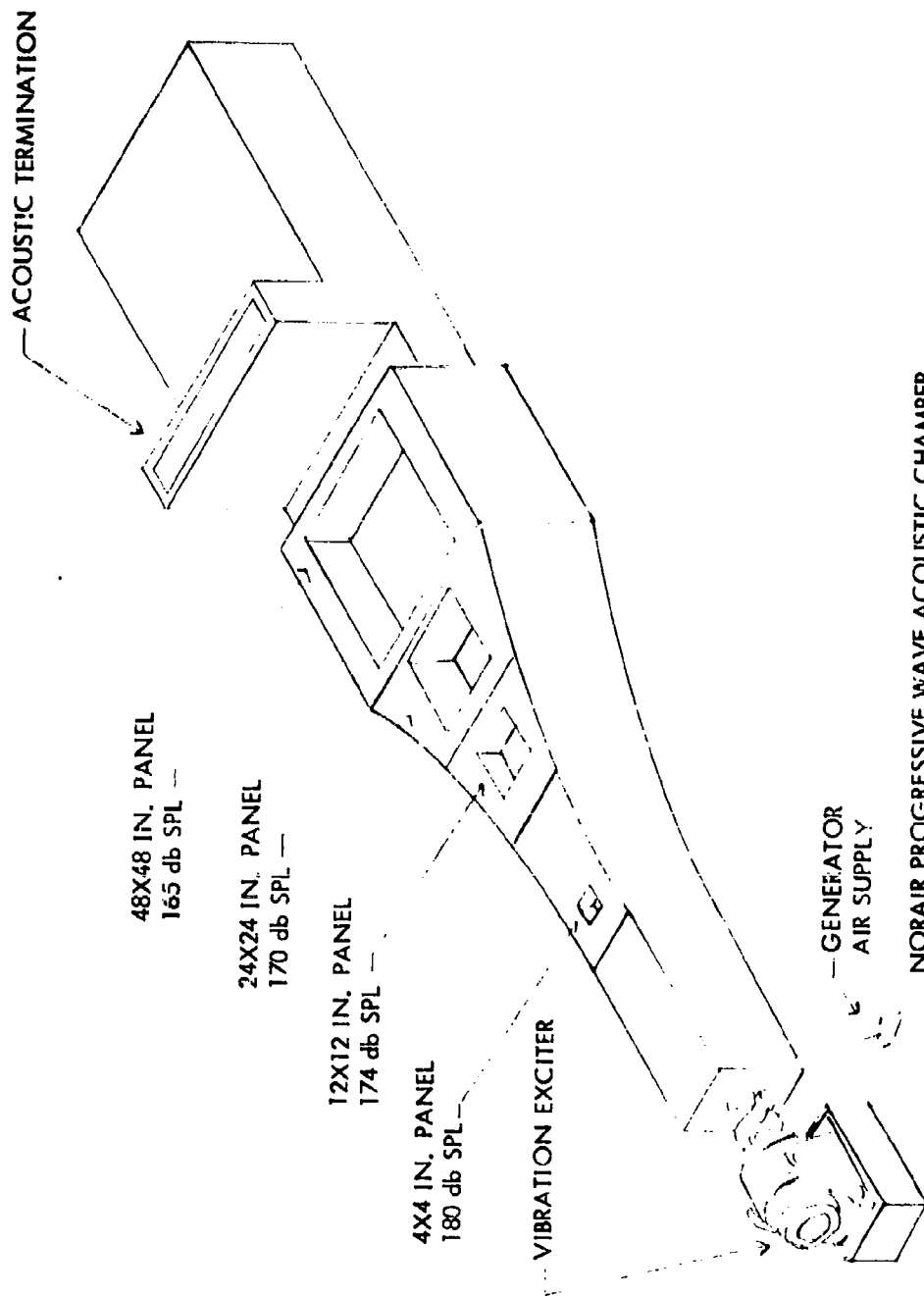


FIGURE III N-1

NORTHROP



REVERBERANT CHAMBER WITH NORAIR GENERATOR

FIGURE III N-2

input to the driver is very rich in higher harmonics. Since the excitation of the driver is of a limited bandwidth, the higher harmonics appearing in the output are relied upon to fill out the spectrum and produce a broad band output. While no details of the characteristics of the random output are available, the upper limit of modulation with present drivers is 450 cps and with this fundamental bandwidth a band of acoustic power up to 7000 cps is produced.

The latest model generator develops an overall acoustic power level of 175 db (re 10^{-13} watts). Through control of the input to the drivers there is a fair degree of control on the shape of the pressure spectral density at the specimen. The maximum obtainable levels are functions of the specimen sizes and is shown in Figure III N-1. Figure III N-3 is a 1/3 octave band plot of the sound spectrum produced by the modulator when driving into a 15 cubic foot reverberant chamber (See Figure III N-2.)

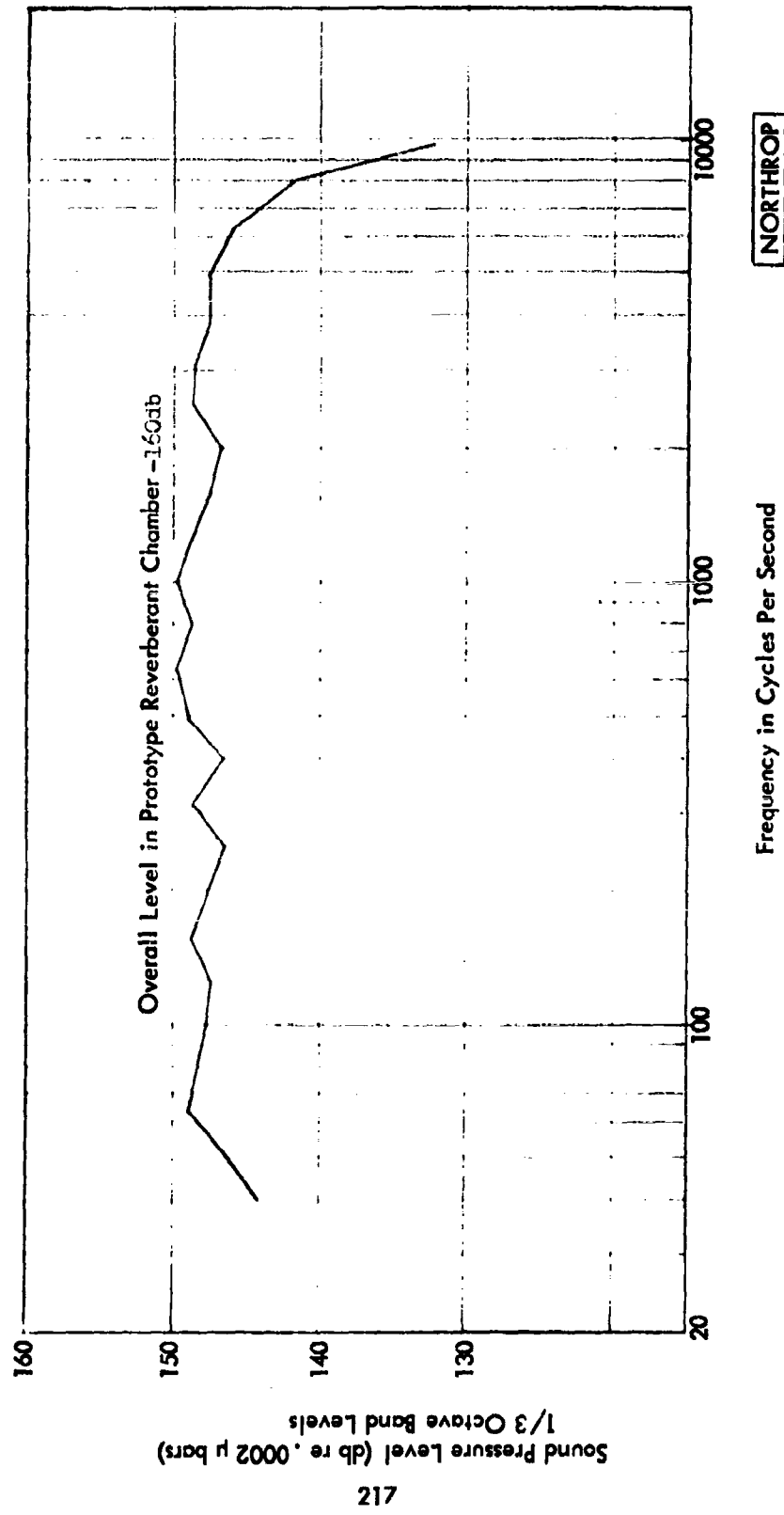
(b) Prototype Progressive Chamber

Figure III N-4 shows a prototype air modulator driving into a rectangular progressive wave chamber. The modulator unit consists of a dual valve chamber with each valve driven by an MBC5 vibration exciter. The flexible hose distributes high pressure air to the valve unit. A plenum chamber, before the modulation, provides a method of smoothing the air flow. Downstream of the modulation valves, a rectangular cross-section horn connects the modulator to the test chamber.

(c) Future Progressive Wave Chamber

A 20' long progressive wave chamber to be driven by the Noraircoustic generator is now under construction. The chamber is to be constructed of reinforced concrete and will be used for sonic fatigue testing of structural panels. (See Figure III N-1 for sketch). The following levels are predicted at the various test sections.

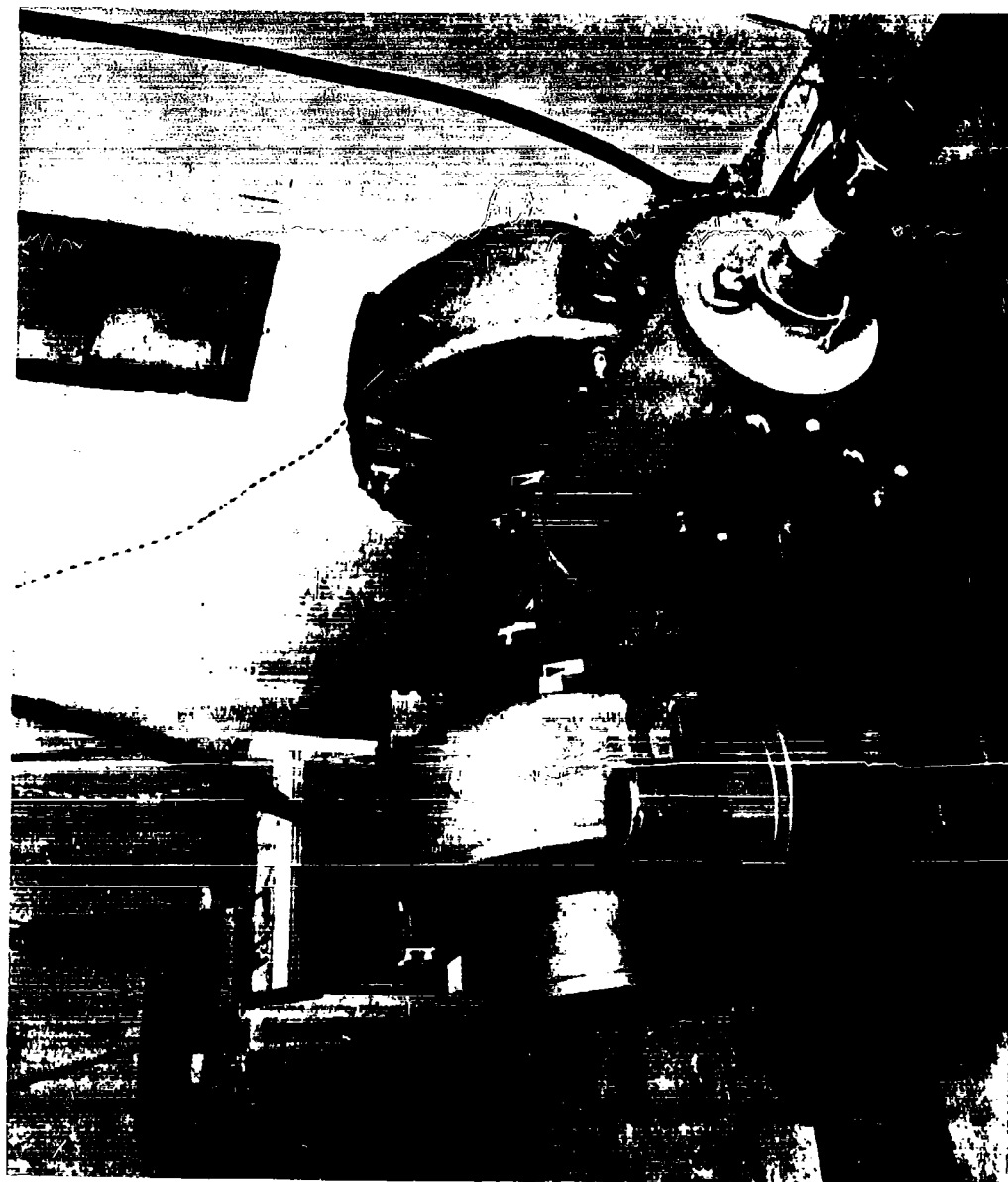
12 x 12 inch panel at	174 db SPL
24 x 24 inch panel at	170 db SPL
48 x 48 inch panel at	165 db SPL



NORAIR AIR MODULATOR FREQUENCY SPECTRUM

FIGURE III N-3

NORTHROP



PROTOTYPE NORAIR GENERATOR

FIGURE III N-4

3. TEST METHODS AND SPECIMEN ARRANGEMENT

Since the generator is broad band, the method of carrying out the test is simply to expose the specimen to the sound field at grazing and sometimes normal incidence until failure occurs or for a given time interval.

An attempt is made to simulate the actual boundary conditions when mounting the specimen in the chamber by choosing a method of fixing the sample edges that most closely matches the operational mounting.

Figure III N-5 shows a prototype generator driving into a 100 cps horn together with a specimen that has been failed with this testing device. This is an instance where the panel was placed normal to the sound field (approximately 170 db on the panel surface).

The maximum panel size that can be tested in the future progressive wave chamber will be 4' x 4'. Failure of a specimen is detected automatically by an electronic system that is sensitive to changes of response — either frequency or amplitude. A pre-test visual inspection is made of all specimens (in some cases a dye check has been used).

4. INSTRUMENTATION AND DATA ACQUISITION

(a) Noise Measurement

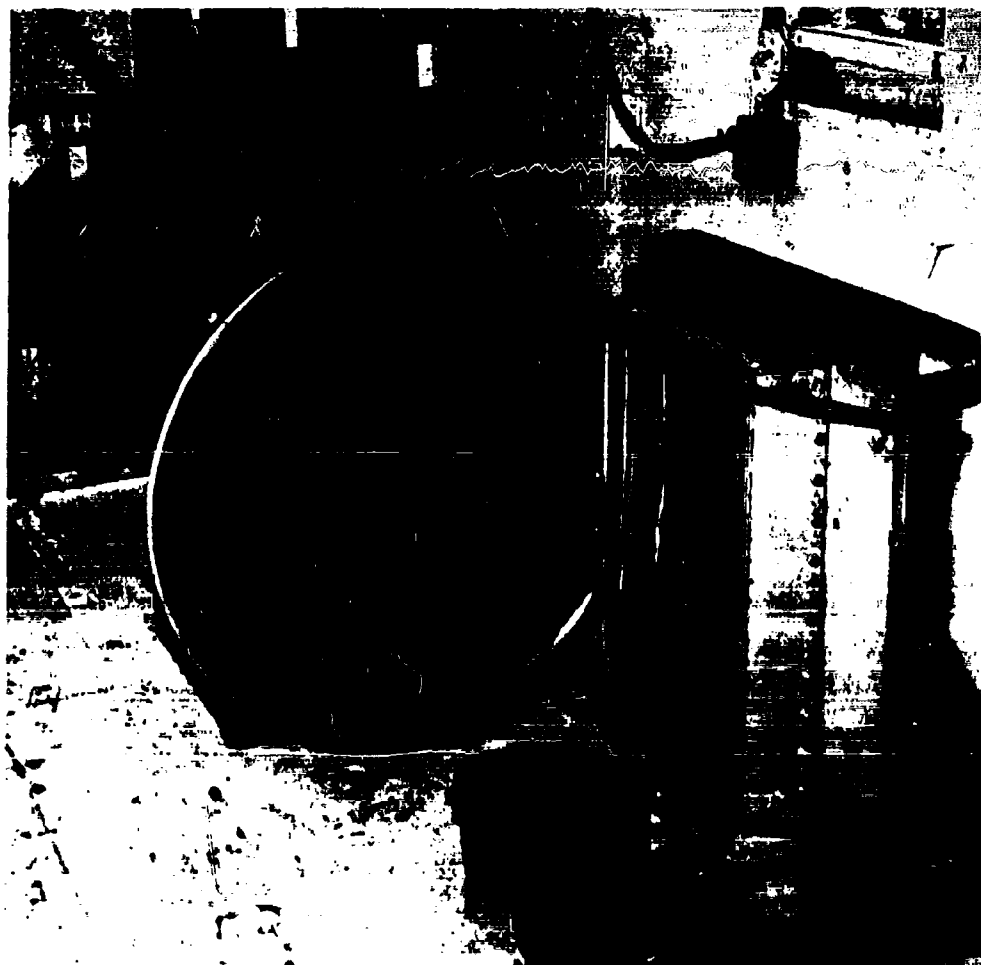
The primary sound pressure pick-up is the Altec 21BR microphone series. A facility for calibrating microphones against a standard microphone is available.

The rms and peak values of the microphone signal are read on Bruel and Kjaer Type 2409 Electronic Voltmeters, and Bruel and Kjaer Type 3312 Spectrum recorders (one-third octave) are used for analysis of the sound spectrum. The Technical Products Spectral Density Analyzer and Plotter (T. P. 525) is available for special cases.

Magnetic recorders (Ampex 350-2) are also available.

(b) Response Measurement

Strain gages are distributed over the panel (number not specified) in an attempt to yield a representative picture of the panel strain response. The spectrum of



PROTOTYPE GENERATOR AND A SPECIMEN FAILURE

FIGURE III N-5

the strain response to a given sound field is monitored. Norair also uses capacitive displacement pick-ups to measure the deflection of panels.

A detailed list of instruments or block diagrams of their relationship was not available when this report was written.

5. INTERPRETATION OF DATA

Purposes of the test program at Norair include fundamental research in metal fatigue, proof testing of new designs, and sub-contract testing for different projects. No accelerated tests are being carried out.

Where possible, a continuous recording of response is made. The test results are summarized by sound pressure level, time to failure, rms stress level, peak to rms ratio, and peak distribution. The index of severity of a test is stated to be the energy acceptance of a panel. The index of fatigue life is time to failure. No cumulative fatigue theories are used. Curves or other summary information for representative test runs are not available since the facility has not been in full operation yet. No significant data is available on fatigue test results in comparison with service life in actual environments.

6. TIME AND COSTS

The approximate cost of the complete facility is estimated to be \$40,000.00. The maximum operating cost is \$25.00 per hour. For a given panel configuration 3 or more specimens are generally used. A 3 specimen program would require approximately 3 weeks and would cost approximately \$2,500.

7. COMBINED ENVIRONMENT TESTING

Combined tests of temperature, vibration, shock, and high intensity noise are in the planning stage and no detailed information is available. At the present time, Norair is working on a "hyper-environment simulation" study on Contract No. AF33(616)-6679. Part II of this report will have some discussion on the necessity of combined testing.

8. BIBLIOGRAPHY OF RELATED REPORTS

SKILLING, D. C., Norair Modulator Acoustic Generator NB60234, 16 August 1960

Abstract

This report contains a brief description of the air modulator acoustic generator that is used by Norair.

III-P. WRIGHT AIR DEVELOPMENT DIVISION **DAYTON, OHIO**

1. GENERAL DESCRIPTION

This installation, which will be the largest sonic fatigue test facility in the world, is designed for the performance of programs in research and development and proof tests on flight vehicle structures and components. Some of the tests or programs that are planned for the facility include:

(a) Research Tests

- Linearity of Structural Response
- Fatigue as a Function of Peak Pressure Distribution
- Stress as a Function of Spatial Correlation of the Pressure Field over the Specimen
- Fatigue for Single and Combined Modal Excitations
- Stress Concentrations in Skin Attachments and Substructures
- Statistics of Panel Stresses Associated with Construction Variability

(b) Development Tests

- Fatigue Strength of Various Materials (Stress-time curves)
- Fatigue Strength Relevant to Strain Sensitivity (stress-time curves and their functional dependence on microphysical parameters)
- Comparison of Responses of Various Panel Designs (to choose the best generic designs)
- Stress Concentrations in a Generic Panel to Improve the Design

(c) Proof Tests

- Time-to-failure of Actual Panels or Structures (or failure-free performance for a stated time)
- Location of Failure Areas on Actual Panels or Structures to Determine Weak Points of the Structures

A floor plan of the facility is shown in Figure III P-1. This sketch shows the

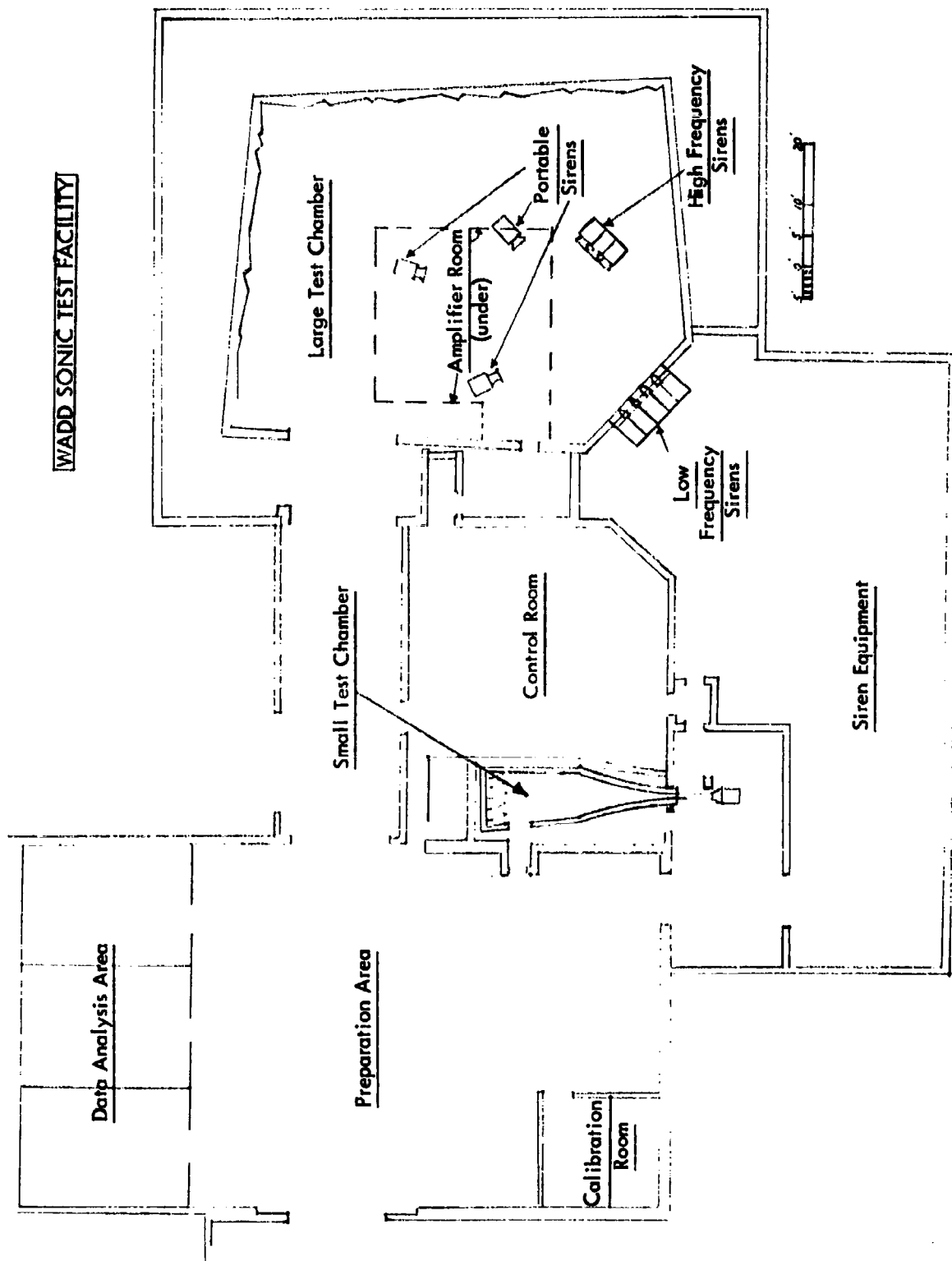


FIGURE III P-1

relationship between the major areas of the facility (the area functions as shown in the sketch are self-explanatory). All the actual testing will be carried out in the large and small test chambers.

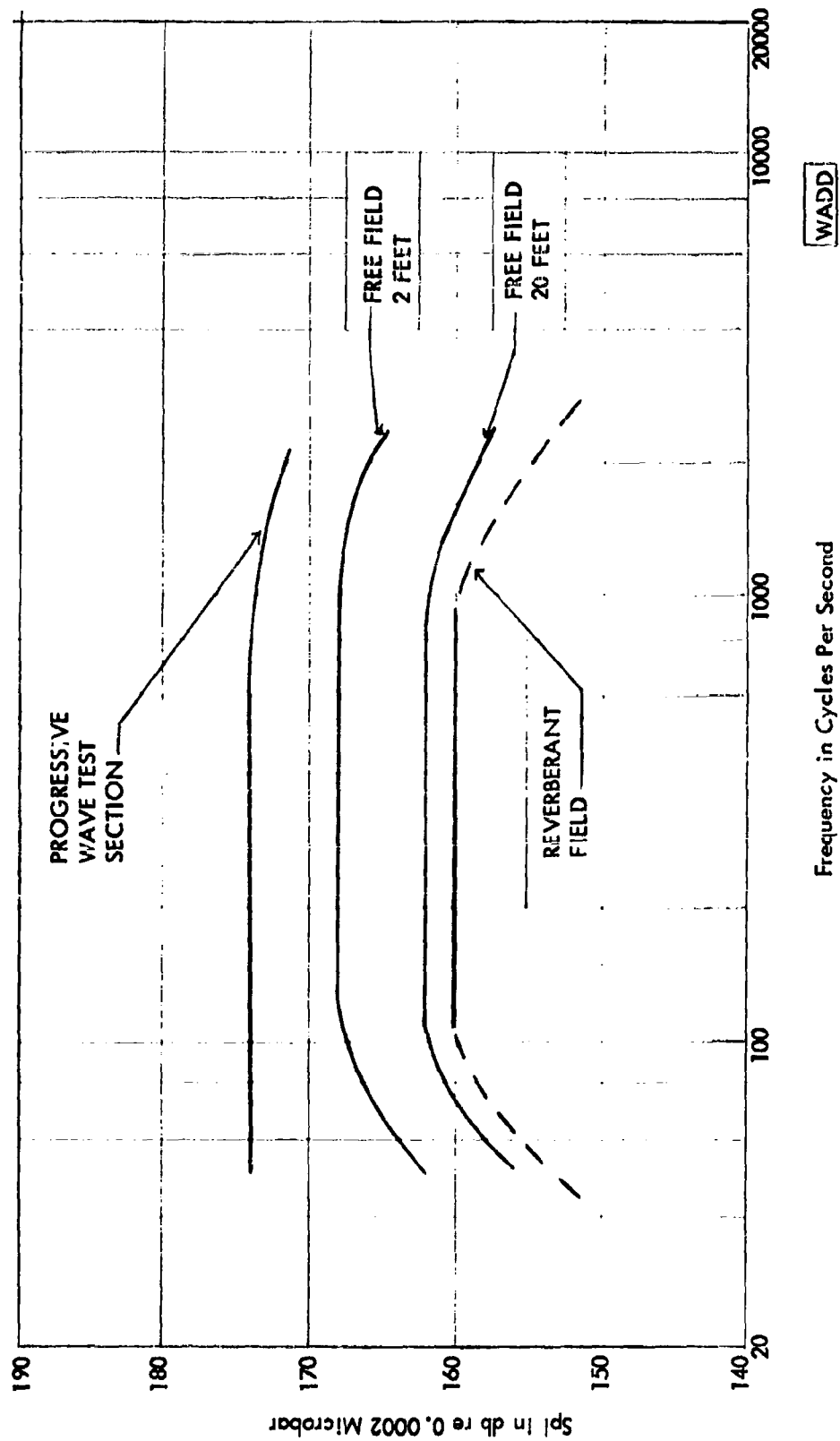
The large chamber (70 feet by 50 feet by 40 feet high) with a large access door (16 feet by 18-1/2 feet) will accommodate test specimens more than 50 feet long.

This test chamber is a reverberant room with an average absorption coefficient of 0.02. To make this reverberation chamber anechoic for progressive wave testing, sound absorbing material will be positioned over the inside wall surfaces. The anechoic material, when not used, will be removed and stored. The estimated performance of the anechoic treatment (shown in Figure III P-2) was obtained from measurements on an experimental scale model. The principal sound sources for this chamber are a bank of 25 pure tone low frequency sirens and a bank of 9 pure tone high frequency sirens.

The small test chamber will be used for carrying out sonic research on test specimens that are approximately 1 foot by 2 feet or smaller. It has been designed for progressive wave testing and is similar in size and operation to the prototype facility at Bolt Beranek and Newman, Incorporated (for details of prototype see BBN facility description). The siren sound source consists of two sirens, one low frequency and one high frequency unit identical to the sirens used in the large chamber.

In the large test chamber an existing 40,000 HP motor will be used as the power source for the sirens' air compressor. The motor will run at speeds of from 300 rpm down to 80 rpm for delivery of maximum to minimum required air flow, and the compressor will deliver 310,000 cfm of inlet air at a compression ratio of 2. The compressor (an axial flow type) will consist of approximately 5 stages with fixed blades and will be run at a rotor speed of 3600 rpm at rated output. Reduced flow and discharge pressure (from 10 psig to 0.05 psig) will be obtained by reducing the speed of the motor. When the large test chamber is used for reverberant testing, the humidity will be controlled to minimize the attenuation of sound by the air. The air train has been designed based on a once-through operation with a humidifier that cools as well as humidifies.

For the small test chamber, a 1250 HP motor and compressor will be used as



MAXIMUM SOUND OUTPUT FROM MAIN BANK OF 25 SIRENS

FIGURE III P-2

the air supply. The motor is an induction squirrel cage type with essentially constant speed characteristics. The compressor will deliver 10,700 cubic feet of air per minute measured at inlet conditions and will be capable of delivering 31 psig at discharge. A humidifier will also be provided to increase the relative humidity of the compressor discharge air to an amount that will yield 60% relative humidity or more in the test chamber.

2. TYPES OF SOUND SOURCES

(a) Large Chamber

The principal sound source for the large chamber is a bank of 25 pure tone sirens (harmonic down 20 db) that can be operated together synchronously or independently. The bank of sirens (positioned in the wall at one corner of the large chamber) forms a sound radiating surface 12-1/2' x 12-1/2' square. The operating frequency range for these sirens is from 50 cps to 2400 cps. In Figure III P-2, estimated performance is presented for 3 modes of operation; a random sound field, a progressive sound field at two locations in the chamber, and the sound pressure obtained in a special progressive wave test section attached to the siren bank.

The 25 sirens may all be operated synchronously to emit a sound power output of one megawatt in the frequency range between 100 cps and 500 cps. It is possible to use the siren amplitude modulators to extend the lower frequency range down to DC.

With the large chamber used as a reverberant enclosure a maximum sound pressure level of 160 db in the frequency range from 0 cps to 1000 cps is expected. The major portion of the testing in this facility, however, is expected to be done with progressive sound waves at full output. The main siren bank will emit a progressive wave with a sound pressure level of 168 db at 2' and 162 db at 20' from the sound source. Special horns may be connected to the main siren bank to obtain a maximum sound pressure level of 174 db in a progressive wave test section in the frequency range between 50 cps and 1000 cps, over a test area 1-1/2 feet by 12-1/2 feet.

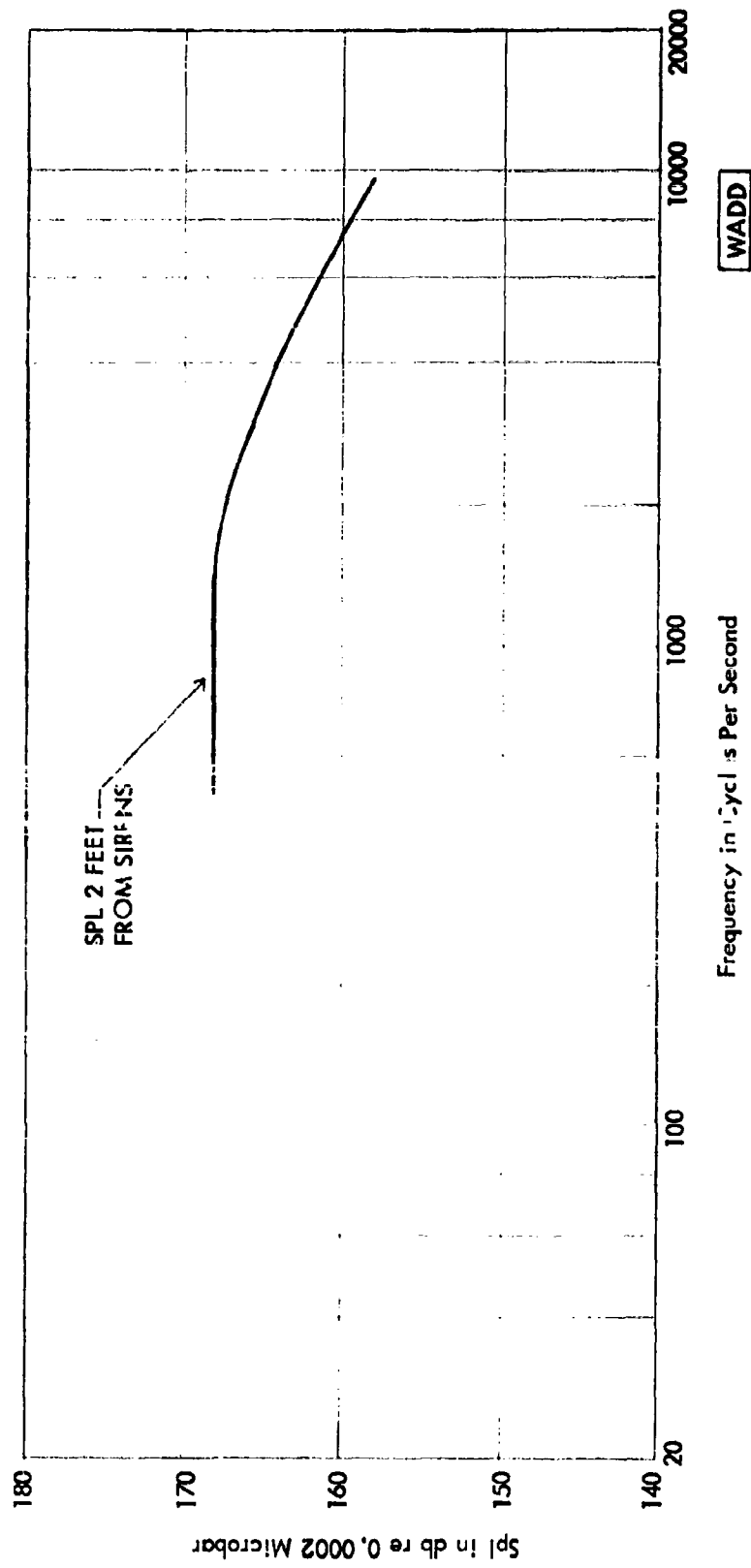
To perform tests at frequencies above 2400 cps, a secondary bank of high

frequency sirens is used. The high frequency sirens will cover the range from 500 cps to 10,000 cps. Nine high frequency sirens are grouped together to give a sound radiating surface $4\frac{1}{2}' \times 4\frac{1}{2}'$. The high frequency bank is semi-portable and can be positioned at various locations in the large chamber. It has a maximum sound power output of approximately 90,000 watts. The maximum sound pressure level obtained at high frequency is shown in Figure III P-3.

The high frequency and low frequency sirens are similar in design and construction. They produce single tones within their frequency range with the harmonic content down approximately 20 db. Each low frequency siren has a maximum acoustic power output of approximately 40,000 watts. The individual high frequency sirens have a maximum acoustic output of approximately 10,000 watts.

All of the sirens in the large test chamber can be operated simultaneously with independent speed control. The frequency of each siren can be controlled to within 1% of the desired frequency by supplying the correct voltage (from 0 to +1v) to the siren speed control system. When the sirens in the low frequency or high frequency bank are operated in a synchronous mode, the maximum relative phase shift in the acoustic signal radiated from the individual sirens is to be less than $\pm 45^\circ$. Each siren in the facility has a separate air control valve that is manually operated from the control room. This valve is used mainly for turning the siren on or off but can also be used as a coarse amplitude control.

The sirens have special provision for amplitude modulation control. The modulation is achieved by varying the area of the stator ports by means of a modulator disc which is concentric with the stator axis and which can be cycled through a small angle to vary the open area of each stator port simultaneously. The modulator disc can also be set to give a static control over the amplitude of the siren (ranging approximately 50 db). In actual siren models, the frequency of modulation of 30 cps for a low frequency siren and approximately 70 cps for a high frequency siren have been obtained. Amplitude modulation of the siren output can be used to simulate a narrow band of noise and to control the peak-to-rms ratio of the output signal. The dynamic performance of the



MAXIMUM SOUND OUTPUT FOR HIGH FREQUENCY SIREN BANK

FIGURE III F-3

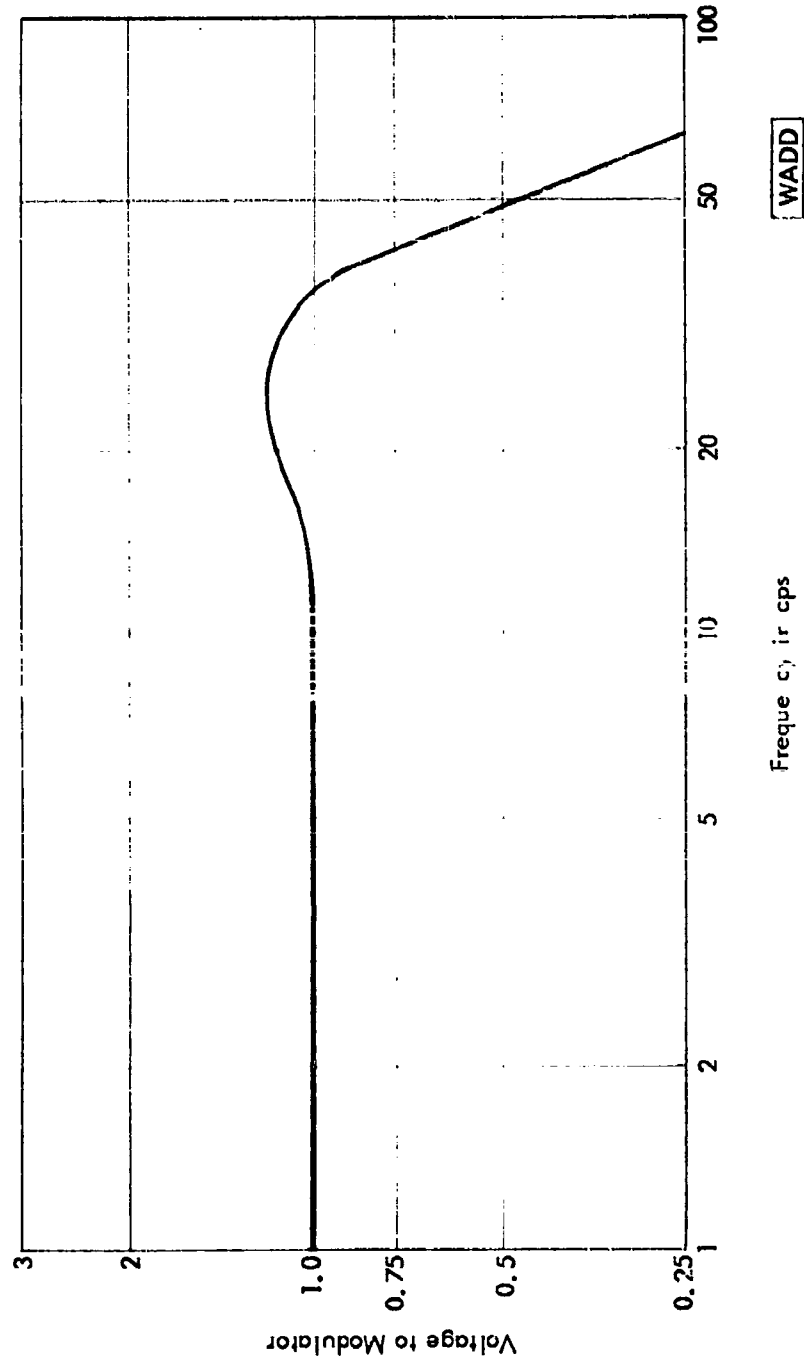
modulator in the low frequency siren is shown in Figure III P-4. The modulator in the high frequency unit is smaller in size and provides a similar frequency response at approximately twice the frequency.

There are two additional portable sirens in the large chamber. There is a low and a high frequency pure tone siren identical to the sirens described earlier. These two sirens are powered through flexible hoses and cables so that they can be moved within the test chamber. The low and high frequency pure tone sirens are controlled in the same manner as the sirens in the main siren bank and have a maximum acoustic output of 40,000 watts and 10,000 watts respectively.

A broad band siren of the type developed at the Aero Medical Laboratory, WADD, may be utilized. This siren consists of a single nozzle and 4 overlapping rotors with randomly spaced teeth passing in front of the nozzle. The rotors pass in opposite directions with non-commensurate peripheral speeds so as to interrupt the air stream aperiodically. Each rotor is capable of cutting off the air stream independently from the others. The air flow resulting from this type of chopping action has frequency components which are harmonics of the blade passage frequency of the individual teeth of each rotor and other frequency components which are products of the frequency produced by separate rotors. The spectrum based on a third octave band analysis is filled with a relatively even distribution of components over a wide frequency range when tooth spacings are optimized. A third octave band analysis of the siren, with and without a horn, is shown in Figure III P-5. Figure III P-6 shows the peak pressure distribution with the siren in a free field and the pressure distribution of a free field jato rocket.

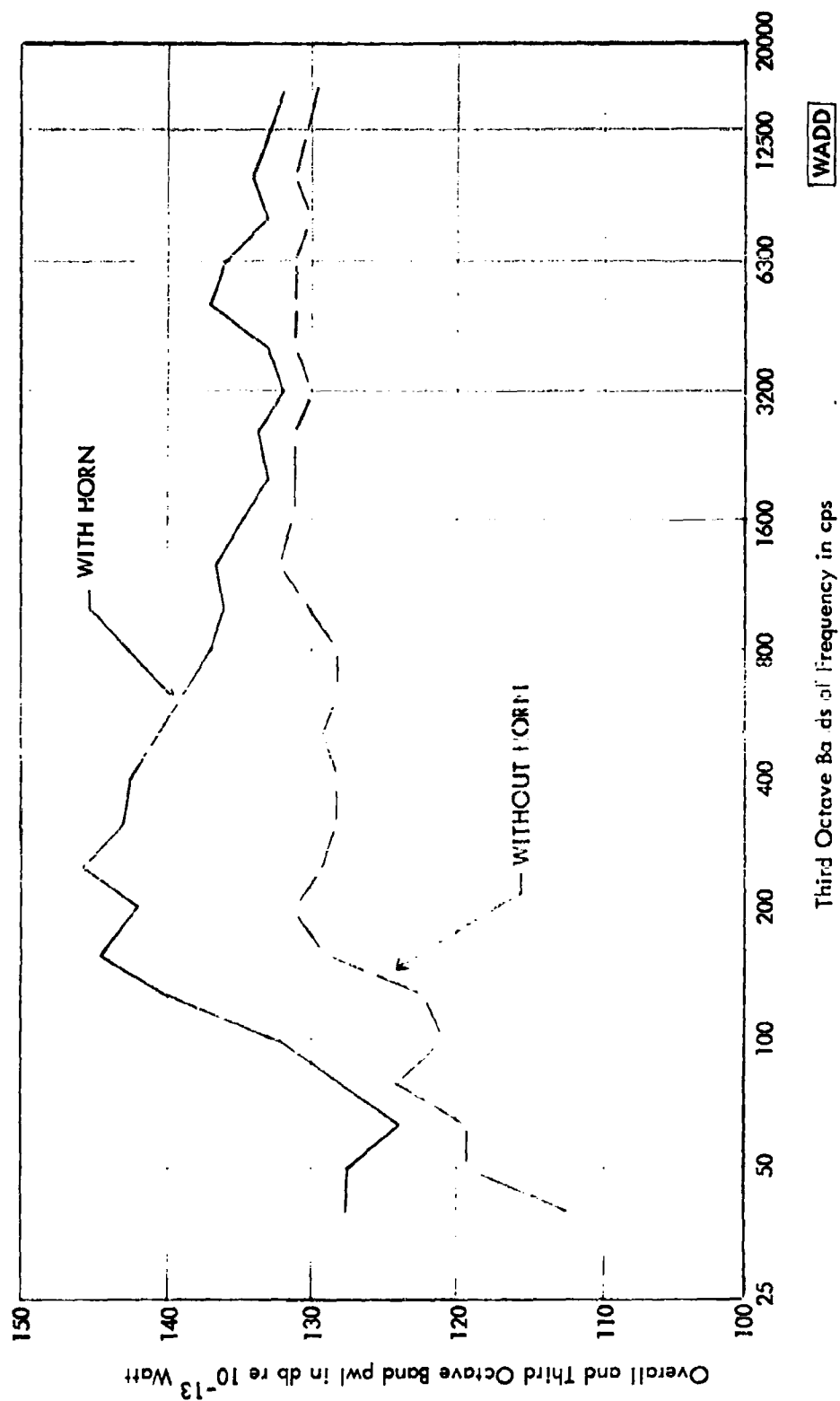
(b) Small Test Chamber

The sound source for the small chamber consists of one low frequency and one high frequency siren (similar to the large chamber sirens). The small test chamber is similar in size and operation to the prototype sonic test facility in Cambridge, Massachusetts. Figure III P-7 shows the maximum single frequency sound pressure level available in the 1 foot square progressive wave test section. The two sirens have been



DYNAMIC PERFORMANCE OF LOW FREQUENCY SIREN MODULATOR

FIGURE III P-4



THE EFFECT OF HORN LOADING ON ACOUSTIC POWER SPECTRUM

FIGURE III P-5

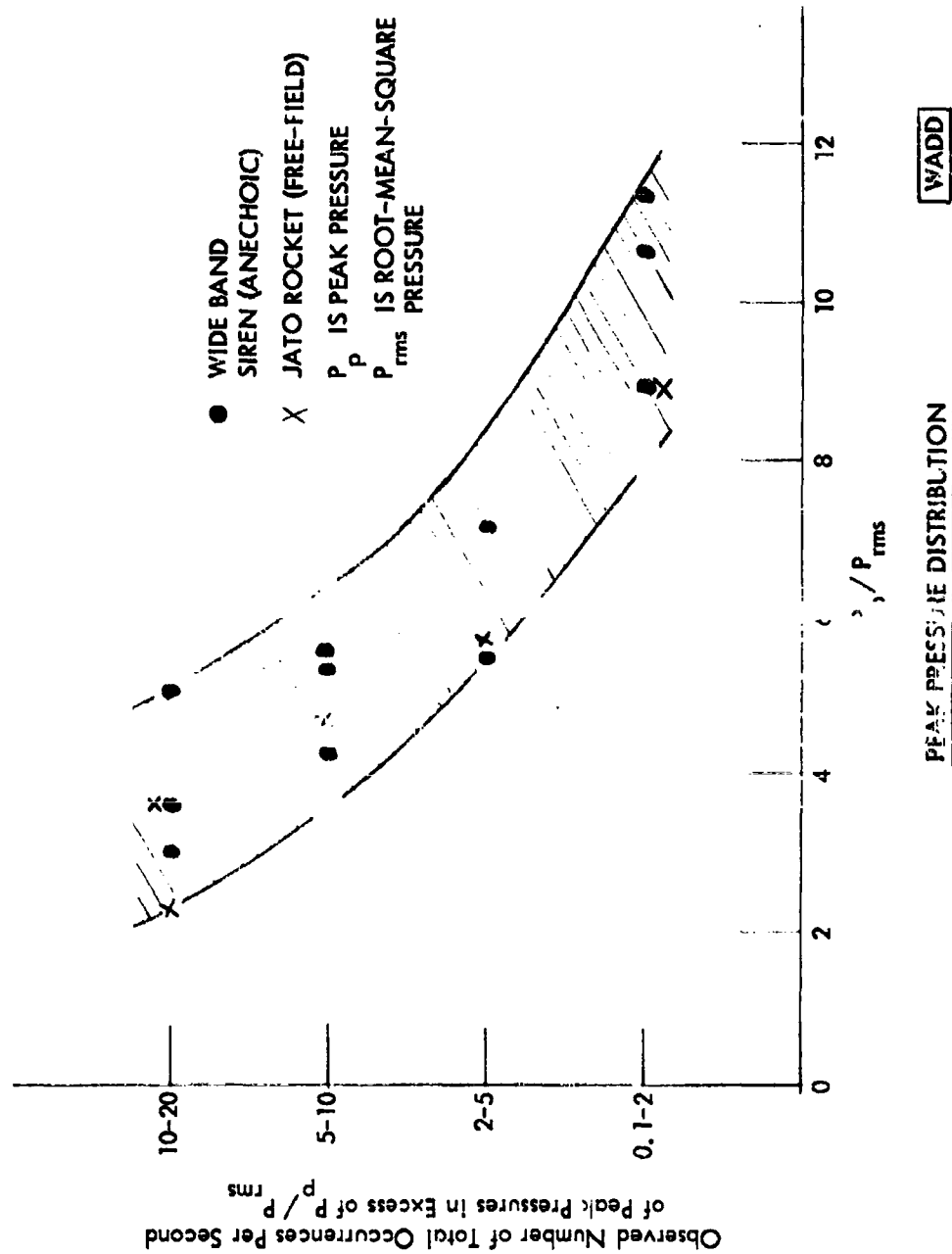
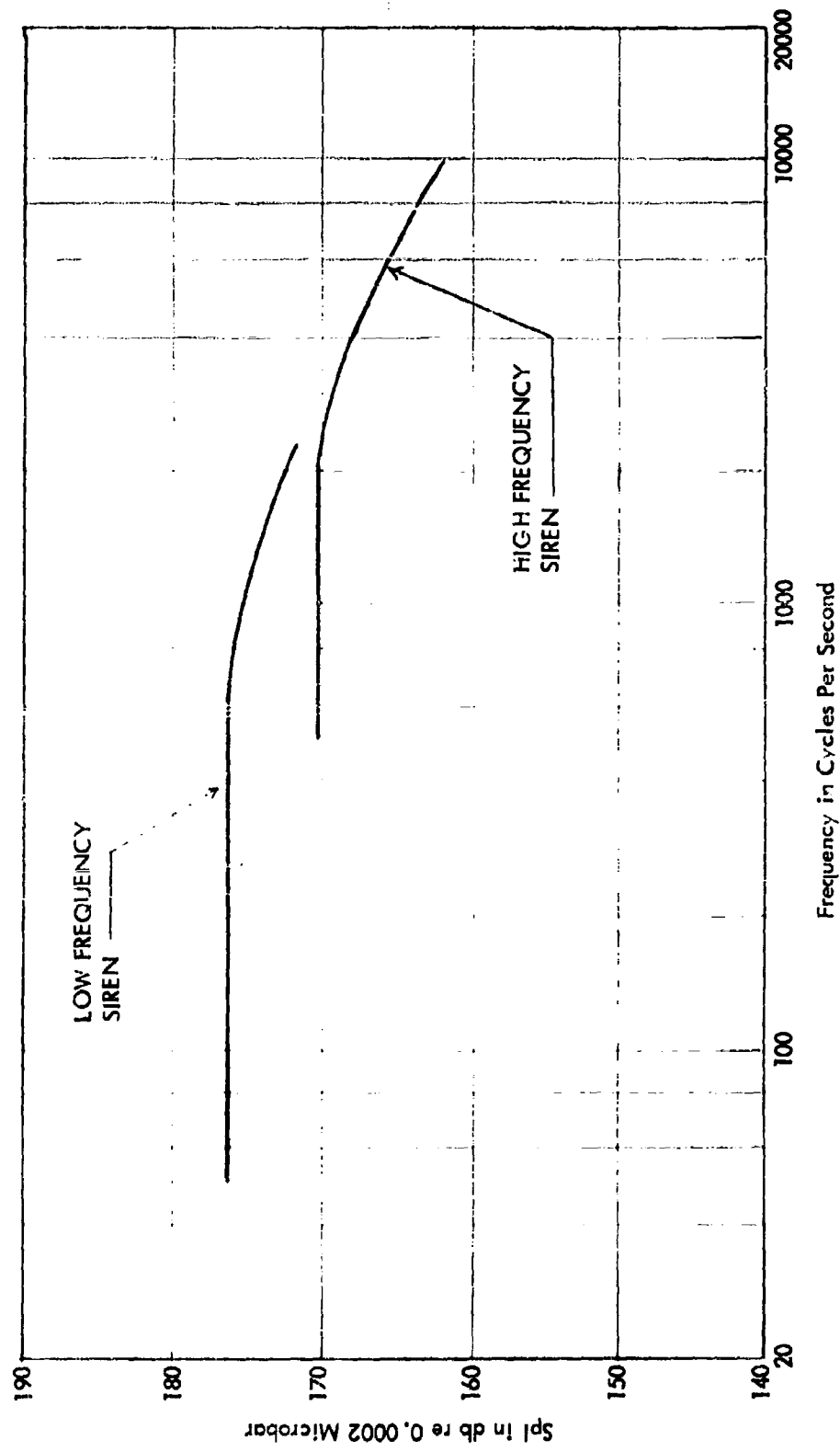


FIGURE III P-6



MAXIMUM SOUND PRESSURE LEVEL IN THE SMALL CHAMBER 1 FT. SQ. PROGRESSIVE WAVE TEST SECTION

FIGURE III P-7

WADD

arranged to operate either separately or simultaneously. The large siren is positioned immediately at the end of the test section and directed axially along the test section itself. The high frequency siren is positioned at right angles to the test section and its sound is reflected by means of a 45° mirror in the test section. When the low frequency siren is operated alone, the mirror is removed; when the high frequency siren is used alone, a solid mirror is inserted, and when both sirens are operated simultaneously, a semi-transparent mirror is inserted. This facility is expected to provide a progressive wave field for testing small specimens at sound pressure levels of 180 db. To provide a termination such that a progressive wave field is closely approximated, a large horn with a low frequency cut-off to match the test section exit area with the termination room entrance area was designed. The termination chamber is lined with acoustic absorbing material at the far end to prevent reflections. Performance data for this facility will be very similar to that of the BBN facility described in Section III-C.

3. TEST METHODS AND SPECIMEN ARRANGEMENT

The large test chamber has been designed to handle full scale test specimens. This will include testing of a large portion of a liquid-fueled missile. It is planned to fill the missile tanks with water to approximate the loading effects of the rocket fuel. When the facility is completed, the chamber will provide a reverberant and free field testing capability.

The specimens for the small test chamber will be approximately 1' x 2' in size. This chamber has been designed primarily for progressive wave testing. However, random incident wave testing can be performed if the anechoic termination is removed from the chamber. Normal incidence testing at reduced noise levels can also be done using larger specimens by locating them at various places in the horn section or in the termination room itself.

No specific information is available as to the precise way specimens are to be mounted or instrumented. This is to be expected, however, since each proof test in the large chamber will be a major undertaking that will require special consideration. Also, most of the tests in the small chamber will be of a research nature so that the

requirements of each test will determine the mounting and instrumentation.

It is planned to use the preparation area for performing low-level sonic and vibration testing prior to installation of the test specimen in either the small or large chambers. Several portable loudspeaker and amplifier combinations are available for doing low-level testing in the preparation room and in the large chamber. These portable sound sources will be used to determine some of the major modal patterns on a test specimen, and also to determine the location of transducers to be mounted on the specimen.

4. INSTRUMENTATION AND DATA ACQUISITION

The control room contains the sound source control instrumentation and the specimen monitoring instrumentation needed for conducting sonic tests in either the large or small test chambers.

(a) Testing in the Small Chamber

The control console for the small chamber contains the frequency and modulator controls for the low and high frequency siren, siren air pressure control for the 1,250 horsepower compressor, plus controls for a 4-channel and 14-channel data tape recorder. The 4-channel recorder may be used either to program the operation of the two sirens or for recording data from transducers mounted on the test specimen.

The monitoring instrumentation includes oscilloscopes, voltmeters, several types of filters, plus the necessary amplifiers and accessories for measuring sound pressure level, acceleration, and strain on specimens.

(b) Testing in the Large Chamber

The controlling and monitoring of a test conducted in the large chamber is accomplished within a circle of instruments in the control room. Half of this circle contains the record level monitoring meters for the data tape recorders and the numerous types of specimen monitoring instruments. A control console in front of this monitoring instrumentation contains the manual controls for the sirens, controls for the data tape

recorders, and the signal distribution patch panels. The other half of the instrumentation circle along with its attendant console contains the controls for the small and large air compressor, the air pressure control systems, temperature indicators, and automatic sequence programmers for automatic operation of the entire facility.

(c) Control Systems

Automatic sequence programmers control the starting operation of both the small 1, 250 horsepower and large 40, 000 horsepower compressor. These two air supplies have many accessories such as pumps, valves, etc., that must be started and stopped in a preferred sequence. There are two sequence programmers — one for each air supply.

At the siren control console for the large chamber, the siren frequency, siren modulator, and the siren air shut-off valve can be monitored and manually controlled for all sirens. An auxiliary control from a pre-programmed tape recording or other device may also be superimposed upon the manual frequency and modulator controls to permit automatic variation of the siren rotor and modulator signals. This mode of semi-automatic operation is used to operate the sirens all at different frequencies with a pre-determined amount of frequency and amplitude modulation to approximately simulate a broad-band noise.

There are numerous types of signal generating equipment available in the control room for making up tape programs to operate the siren frequency control system. A 4-channel tape recorder is available for recording and can be operated at a convenient low speed when the program is being prepared. The playback can be at a much higher speed for controlling the sirens during an actual sonic test.

To synchronize the siren frequency with one or more of the resonant frequencies in the specimen, the signal from a strain gage or accelerometer on the test specimen is monitored by the siren control system. Also, the signal from a microphone mounted in the immediate vicinity of the strain gage or accelerometer is monitored. The operator at the siren control console manually adjusts the frequency of the siren for maximum

response in the specimen at its resonant frequency. The phase of the signal from the transducer on the specimen is then manually compared with the signal from the microphone, and the phase of one of these signals is adjusted to the phase of the other signal. The control of the siren frequency is then transferred from "manual" to automatic control by means of the signals from the transducers on the specimen. The siren frequency now follows minor changes in the resonant frequency being excited in the test specimen. Sufficient instrumentation is available to operate the sirens at four independent resonant frequencies in the test specimen simultaneously.

(d) Noise and Response Measurement

The majority of the transducers involved in specimen monitoring are for the measurement of sound pressure level, acceleration, strain, and temperature. These transducer signals, except temperature measurements, normally will be recorded on magnetic tape during a sonic test. The temperature information is displayed on conventional chart recorders. Iron-constantin thermocouples are planned for the bulk of the temperature measurements in the facility.

The specimen monitoring instrumentation (covering a bandwidth of DC to 10,000 cps) has been designed so that no electronic equipment other than the transducer itself is required to operate in the test chambers in the presence of high intensity noise. The monitoring transducers are connected to the amplifier room underneath the test chambers via special "low microphonic" cables. Piezo-electric transducers are used to measure sound pressure and acceleration, and strain measurements are made with conventional low impedance strain gages.

A large selection of standard monitoring instruments is available in the control room for observing the response of the test specimens in the large chamber. These instruments include a wide frequency range multi-channel oscillograph; oscilloscopes; voltmeters which can respond to the peak, rms, or average value of the signal; harmonic frequency analyzers; adjustable band pass filters; audio monitoring; and closed

circuit television.

The tape recording instrumentation will handle signals in the frequency range from DC to 10,000 cps. The data from typical sound, acceleration, and strain transducers may be recorded continuously for a few seconds to several hours. When several transducers share one common recording channel, the signals from these transducers are each sampled for a specific pre-determined duration controllable from 1 to 15 seconds. A code signal is also recorded to identify the transducer being recorded.

The signal conditioning equipment and amplifiers are nearly identical for all data channels. This was done to minimize the phase distortion between two or more data channels. With this system the amplitude error is less than ± 0.5 db from DC to 10,000 cps, and the phase error is less than $\pm 5^\circ$ from DC to 1,000 cps, and less than $\pm 30^\circ$ between 1,000 cps and 10,000 cps. This performance includes the data tape recording and reproduction process.

(e) Data Analysis Systems

Some analysis of the tape record signals can be performed in the control room. There is a multi-channel tape loop recorder available to accommodate the full signal capability of any data tape recorder. An automatic tape searching device is useful for selecting the specific signal on the data tape for transference to the tape loop recorder. When a detailed analysis is desired, the tape recorded information is taken to the data analysis area in another part of the facility.

The data analysis area consists of three rooms. One might be called a "quick look" type of analysis or editing room. The second is for more detailed analysis and the third room is for translating the analog acoustic data into a digital form.

The edit room contains one multi-channel recorder for reproducing the data acquired on the recorders in the control room. Sonic test data may be reproduced to review the test results and to edit the recorded data for further detailed analysis. This room has facilities for displaying twelve channels of recorded information simultaneously on a wide frequency band oscillograph. There are also oscilloscopes and meters for

observing the recorded information.

The detailed analysis room contains instrumentation not available elsewhere in the facility. In addition to the usual monitoring instruments like oscilloscopes and meters, there is instrumentation for performing octave band, one-third octave band and narrower band frequency analysis, power spectral density analysis, cross-correlation analysis in the time domain and amplitude distribution analysis.

The data to be analyzed is reproduced from one of two standard tape recorders. One recorder will reproduce twelve data channels (plus two code channels) from 1 in. tape and the other two data channels from 1/4 in. tape. Signals from these recorders can be re-recorded onto two tape loop recorders with the same number of data channels.

The detailed analysis instrumentation incorporates semi-automatic modes of operation. The frequency analysis instruments include octave band, one-third octave band and narrower bandwidths down to approximately 1 cps. The combined octave and one-third octave band analyzer contains continuous filters that have effective bandwidths equal to a constant percentage of the center frequency of each filter.

The analyzer gives the integrated rms value of the energy in one filter band for each complete passage of the data signal reproduced from the data tape loop. The analyzer has a nominal frequency range from 20 cps to 10,000 cps., and the analyzed spectrum information is presented on standard 8-1/2 x 11 graph paper with an amplitude scale of 10 db/inch on the ordinate and a log frequency scale of 3 inches/decade on the abscissa.

The power spectral density analyzer is basically a constant bandwidth filter with continuous tuning throughout its frequency range. There is a variety of filter bandwidths to choose from between 1 and 100 cps.

The speed of analysis of the constant bandwidth analyzer is usually much slower than the constant percentage bandwidth analyzer because of its relatively narrow bandwidth. The power spectral density analyzer can present the analyzed data in the form of the mean-squared signal on an equivalent 1 cps wide bandwidth over a continuous linear frequency range. There are two basic restrictions on the speed of analysis possible

with this type of instrument. To obtain accurate information describing the signal, it is necessary to scan the frequency range at a rate less than one effective filter bandwidth per second and also to scan at a rate much less than one filter bandwidth per complete passage of the tape loop.

The cross correlator is another instrument that needs a relatively long time to obtain detailed information. The cross correlator incorporates a time delay mechanism capable of varying the time delay of one data channel with respect to another data channel continuously from 0 to 250 milliseconds. This analysis instrument is used in conjunction with one of the tape loop recorders. The delay time (τ) between two data channels is usually the parameter that is varied by a pre-programmed scanning rate. The cross correlator has the ability to determine the identity of a signal between two data channels to a resolving power of 10^{-5} seconds. Analysis with the correlator is time consuming and it is not unusual that 15 minutes to one hour may be required for one analysis. The analyzed data from the cross correlator is presented on graph paper with the correlation function plotted on the ordinate on either a linear or logarithmic scale. The time delay, τ , is plotted on the abscissa of the graph.

The amplitude distribution analyzer is still another instrument which by its very nature also requires an exceedingly long time to obtain information from the recorded sample when the data of interest lies out in the extreme tails of the amplitude distribution curve. When the amplitude probability density or the peak distribution are of interest to values approximately three sigma or less, the analyzed signal may conveniently be presented graphically in the form of the familiar distribution curve. This type of data can be analyzed in a few seconds and is useful for determining instrumentation overload or other discrepancies in the measuring system. However, probably the most interesting information will lie out in the tails of the distribution curve beyond three sigma. For this information an analog presentation in the familiar form is not useful. Thus, a digital read out is available on the amplitude distribution analyzer. An electronic counter may be used to count the actual events at a given sigma level for a specific data sample length. The counter technique permits an

operator to determine accurately the number and value of the infrequent but important peaks in the signal.

The analog output signal from any of the analyses instruments described above may be translated into digital form on IBM punched cards. The punched cards can be processed through a programmed card sorting machine with the resultant data presented in digital form or reconstructed back into analog form and displayed on graph paper. The card punching and sorting system gives the sonic facility a powerful tool for comparing large amounts of partially or completely analyzed data to ascertain significant and important trends that developed during a sonic test. For example, a narrow frequency range of interest can be presented as a function of time. The trend of the signal from one specimen transducer can be compared with the signal from a different transducer. The possibilities of data processing and inter-comparison are obvious.

Portable instrumentation is available in the facility to perform tests in the preparation area. They are signal generators, loudspeakers, vibration shakers, voltmeters, oscilloscopes, filters, frequency analyzers, graphic level recorders, and tape recorders. The same types of transducers for measuring sound, vibration, and strain in the test chambers will be, in general, adequate for use in the preparation room.

(f) Calibration

A calibration room exists in the facility for calibrating and maintaining the facility instrumentation. Complete calibration apparatus is available for evaluating the performance of transducers. A small anechoic chamber is used for determining the free-field calibration of microphones. This chamber is augmented with a piston-phone for determining the low frequency pressure response of microphones. Vibration shakers and resonant bars are available for the calibration of vibration pickups and strain gages. The substitution of a precision voltage into each strain gage bridge circuit is considered adequate for pre-test calibration of the strain measuring transducers.

A pre-test calibration of each piezo-electric accelerometer and microphone will be made. To calibrate these transducers an acoustic tone of known frequency and

sound pressure level is placed upon each microphone, and an acceleration signal of known frequency and level is applied to the individual accelerometers.

5. INTERPRETATION OF DATA

Since the facility is not yet completed it is too early to discuss methods of data interpretation. In fact, as far as its use as a research facility is concerned, it is somewhat meaningless to talk about interpretation and use of data without knowledge of the specific research project being undertaken. We have mentioned the types of tests that are contemplated for the facility and we repeat them here divided into two categories — failure tests and response. It is obvious from the type of test what kind of data should be collected.

FAILURE

(1) Research tests

- (a) fatigue as a function of peak pressure distribution.
- (b) fatigue for single and combined modal excitations.

(2) Development tests

- (a) fatigue strengths of various materials.
- (b) fatigue strengths relevant to various strain sensitivities.

(3) Proof tests

- (a) time-to-failure of actual panels or structures.
- (b) location of failure areas for actual panels or structures.

RESPONSE

(1) Research type tests

- (a) linearity of panel response
- (b) stress as a function of correlation
- (c) stress concentrations in the skin attachments or sub-structures
- (d) statistics of panel stresses associated with construction variability

(2) Development type testing

- (a) comparison of responses of various panel designs to choose the best generic designs

(b) stress concentrations in a generic panel to improve the design

As far as the data interpretation and use in proof tests on large scale vehicles are concerned, it is clear that very specialized test procedures and data gathering techniques will be set up for the proof tests. If the proof testing is carried to the point where sonic fatigue certification programs are established, very elaborate and detailed procedures for testing will be required. These procedures, the type of data gathered, the methods of interpretation will all be developed from research and testing that is to be performed in the WADD facility and from the work performed in other installations. It may be that some of the methods now used by the aircraft companies for predicting flight life from siren tests will be used in establishing proof tests, but certainly it will require another two or three years before any standard proof test or certification test program can be established in the WADD facility.

6. TIME AND COSTS

The total cost of the facility is estimated between 7 and 9 million dollars. The time and cost of tests, independent of specimen costs, will, of course, vary widely with the chamber used, the various sources used, and the amount of analysis required.

7. COMBINED ENVIRONMENT TESTING

At the present time there are no detailed plans for performing combined environment tests except for elevated ambient temperatures obtained by reducing the amount of cooling of the compressed air supplied to the sirens. The problems of building a sonic test facility of this enormous size are complex enough without adding the complications of additional environments. Some thought, however, has been given as to what additional environments might be duplicated.

- (1) Internal pressure could be applied to specimens to evaluate the effect of such pressure on sonic fatigue. Such tests could obviously be carried on without any special provision being made in the facility.

- (2) Some thought has been given as to the possibility of duplicating flight loads on the specimens, but no simple way of doing this has been determined.
- (3) Heating the specimens by means of direct current heating of the metal or by quartz lamps (there is a fear that quartz lamps would be shattered by the intense noise).
- (4) It is considered very unlikely that the effect of nuclear radiation on the sonic fatigue life of a specimen will be evaluated by a combined test at the WADD facility.

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III-Q SUMMARY OF FACILITIES

The following table is a summary of some of the characteristics of the facilities described and will be a useful reference in Section IV which is concerned with the evaluation of sonic fatigue testing.

		BOEING, Seattle	BOEING, Wichita	Bolt Beranek and Newman, Cambridge, Mass	C
EXCITATION	TEST CHAMBER	Reverberant Semi-anechoic Progressive wave	Semi-anechoic (siren) Free field area (sonic wing)	Progressive wave Reverberant chamber	S S
	SOUND SOURCE	Discrete sirens Modulated air flow speakers	Discrete siren - 4 jet engines on a B-52 wing	2 amp. mod. sirens (1 high freq. and 1 low freq.)	D
	FREQUENCY RANGE	100-200 cps (sirens) 20-9600 cps broad band (speakers)	130-2500 cps Broad band (sonic wing)	50-1000 cps 500-10,000 cps	10 Br
	ACOUSTIC OUTPUT (SPL or W)	160-175 db (sirens) 150-160 db (speakers-8000 w)	170 \pm 5 db (siren) 165 db (sonic wing)	22,000 w. (174 db in 1 sq.ft. test section)	17 16 (j)
RESPONSE	SPECIMEN SIZE	6" x 6" to 24" x 48"	30" x 30" (siren) Full scale (sonic wing)	12" x 24"	Ap Fu
	MOUNTING	Special jigs, Close- tolerance-bolts	Rigid to frame	Various	Bo to
	INCIDENCE	Normal + grazing	Normal (siren) Grazing (sonic wing)	Grazing or Normal	Ne Va
	SEVERITY INDEX	Sound pressure level and stress	Sound pressure level	Not applicable	RM
	NO. OF GAGES	2 to 6	Deflection pick-up + gages (2-4)	Not applicable	Sev
	NO. OF SPECIMENS	2 to 15	4 (minimum)	Not applicable	1 m
DAMAGE	FAILURE DETECTION	Frequency, amplitude, visual	Frequency, amplitude, visual	Not applicable	Wa
	METHOD OF ANALYSIS	Various	None	Not applicable	Mil (Mc con)
	DAMAGE THEORY	Miner's rule and $N_v = N_a (N_A / N_a)^\beta$	None	Not applicable	Min
COSTS	FACILITY COST	\$500,000	Siren - \$20,000	Approx. \$150,000	Jet (wit
	OPERATING COST/ HR	Various	Siren - \$25. (no overhead) Sonic wing - \$30,000	Various	Jet Sire
COMBINED ENVIRONMENT		Temperature and pressure	None	None	Non

	Bolt Beranek and Newman, Cambridge, Mass	CONVAIR, Ft. Worth	CONVAIR, San Diego	DOUGLAS, Santa Monica
(siren) (onic wing)	Progressive wave Reverberant chamber	Semi-anechoic (siren) Semi-enclosed (jet engine)	Progressive wave	Progressive wave
jet engines	2 amp. mod. sirens (1 high freq. and 1 low freq.)	Discrete siren	Discrete siren	Discrete siren
wing)	50-1000 cps 500-10,000 cps	100-2000 cps (siren) Broad band (jet engine)	25-1100 cps	50-1000 cps
g)	22,000 w. (174 db in 1 sq.ft. test section)	170 db (siren) 160-172 db, broad-band (jet engine)	170 db	Approx. 165 db
wing)	12" x 24"	Approx. 36" x 36" (siren) Full scale (jet engine)	22" x 44"	48" x 48"
	Various	Bolting, riveting or welding to airplane support	Various Micarta clamping arrangements to a rigid frame	Oversized specimen to rigid frame (test specimen 20% of total specimen)
ng)	Grazing or Normal	Normal (siren) Various (jet engine)	Grazing	Grazing
rel	Not applicable	RMS stress	Sound pressure level	RMS stress
P	Not applicable	Several	Approximately 4	3 to 4
	Not applicable	1 to 3	2 to 3	Various
ude,	Not applicable	Wave shape, amplitude, visual	Frequency, visual	Frequency, amplitude, visual
	Not applicable	Mile's Analysis (Multi-mode + non-linear corrections)	Mile's (modified)	Mile's Analysis (Multi-mode + non-linear corrections)
	Not applicable	Miner's Rule	Miner's Rule (modified)	Miner's Rule
	Approx. \$150,000	Jet engine facility \$200,000 (without engine)	\$42,000	Not available
head) 00	Various	Jet engine \$500 (no overhead) Siren \$30 (no overhead)	\$25-50 (no overhead)	Not available
	None	None	High and low temperature	None

TABLE III Q - SUMMARY OF FACILITIES

		MARTIN, Baltimore	MARTIN, Denver	McDONNELL, St. Louis	NASA, Langley	
EXCITATION	TEST CHAMBER	Semi-anechoic	Free field (open test area)	Semi-anechoic	Test Cell	F
	SOUND SOURCE	Discrete siren	Discrete and random sirens	Discrete siren	Air jet	E R
	FREQUENCY RANGE	100-3000 cps	30-1000 cps (discrete) 20-2000 cps (random)	150-6000 cps	Broad band	2 3
	ACOUSTIC OUTPUT (SPL or W)	160-170 db	160-172 db (discrete) 166 db (random)	170 db	157 db 170 db (expected)	1 1
RESPONSE	SPECIMEN SIZE	48" x 48"	9 square foot area	20" x 20"	Small to 10 sq. ft.	2 (
	MOUNTING	Oversized specimen mounted to rigid frame	Full scale missile segments	Attempt to simulate actual boundary conditions	Bolted, bonded, sharp, and radius edges	R
	INCIDENCE	Normal	Normal	Normal	Grazing	G
	SEVERITY INDEX	RMS stress	Sound pressure level	Sound pressure level	Stress, Energy acceptance	St pr
	NO. OF GAGES	8	6	Various	Various	V
	NO. OF SPECIMENS	Several	1 or 2 segments	Various	Various	V
DAMAGE	FAILURE DETECTION	Frequency, visual	Frequency, visual	Frequency, visual	Frequency, visual	Fr
	METHOD OF ANALYSIS	Miles	A method to correct for localized loading used with sirens	None	Various	Us an DI
	DAMAGE THEORY	Modified Miner $P_1 N / N_1 = .33$	None	None	Energy method and to evaluate others	Mi mc
COSTS	FACILITY COST	Not available	\$630,000	Not available	\$300,000 (for modifications)	\$5 \$1
	OPERATING COST/ HR	Not available	\$110.(with overhead)	\$25. (no overhead)	\$200-400 (no overhead)	\$5 ov
COMBINED ENVIRONMENT		None	None	None	None	Hi

CONNELL, Louis	NASA, Langley	NORTH AMERICAN Columbus	NORTH AMERICAN Los Angeles	NORTHROP, L. A.	WADD
Anechoic	Test Cell	Progressive wave	Progressive wave	Progressive wave	Progressive wave Reverberant chamber Anechoic chamber
Discrete siren	Air jet	Discrete and Random sirens	2 amp. mod. sirens (1 low freq. and 1 high freq.)	Broad band air poppet valve generator	25 low freq. sirens 9 high freq. sirens 2 portable sirens
6000 cps	Broad band	250-550 cps (discrete) 37.5-16000 cps (random)	50-2000 cps 500-10,000 cps	Not specified	50 - 10,000 cps
157 db	157 db 170 db (expected)	165-175 db (discrete) 173 db (PWL random)	278.7 to 27,870 watts (170 db over 3 sq.ft. area)	175 db (PWL random)	174 db (prog. wave) 160 db (rev. chamb.) 70' x 50' x 40')
20"	Small to 10 sq. ft.	24" x 12" (up to 14' x 4' avail.)	36" x 60"	12" x 12" to 48" x 48"	(Various - small to large missile sect.)
Not to duplicate actual boundary conditions	Bolted, bonded, sharp, and radius edges	Rigid frame	Oversized specimen to rigid frame (test specimen 20% of total specimen)	Attempt to duplicate boundary conditions	Not determined
Normal	Grazing	Grazing	Grazing	Grazing	Various
Pressure level	Stress, Energy acceptance	Stress and sound pressure level	RMS stress	Energy acceptance	Not determined
1000	Various	Various	3 to 4	Not specified	Not determined
1000	Various	Various	Various	3	Not determined
Amplitude, frequency, visual	Frequency, visual	Frequency, visual	Amplitude, frequency, visual	Amplitude, frequency, visual	Not determined
	Various	Use both Douglas and Convair, San Diego methods	Mile's analysis (multi-mode + non-linear corrections)	None	Not determined
	Energy method and to evaluate others	Miner's and modified Miner's	Miner's Rule	None	Not determined
Available	\$300,000 (for modifications)	\$58,000 (discrete) \$12,000 (rand.siren)	\$338,000	\$40,000	7 to 9 million dollars
No overhead	\$200-400 (no overhead)	\$50 to \$100 (no overhead)	Not determined	\$25. (no overhead)	Various
	None	High temperature	Vibration and Temperature	None	Not at present

IV EVALUATION OF SONIC FATIGUE TESTING

IV A. USES OF FACILITIES

Sonic fatigue facilities are used for three main purposes -- designing, proof testing, and research and development -- and it is useful to set up distinctions between these various uses.

As was mentioned in Section one the distinctions may not be sharp but they are important. A "facility used for design" is one in which detailed design configurations that can resist sonic fatigue are developed by means of analysis and testing or by means of comparisons of structures exposed to high intensity noise. A "facility used for proof testing" is one in which the configuration is tested by exposing it to noise that simulates in some reasonable fashion the noise environment the structure will experience throughout its life. The design tool use implies fairly quick (or inexpensive) tests on a number of small specimens that will permit the general structure of the vehicle to be established while proof testing implies a rather lengthy (or expensive) test on sizeable segments of the vehicle or perhaps the entire vehicle. Cost is one of the primary reasons for the existence of the two types of facilities rather than only one -- the proof testing installation. A simple discrete frequency siren installation can be built for less than \$100,000 and might cost \$50 per hour to operate while a typical jet engine test installation would cost about \$300,000 to build and about \$500 per hour to operate. Existing facilities may vary widely from these costs but these figures do give an indication of the comparative costs of discrete frequency siren testing (a common design tool) and jet engine testing (a common proof testing tool) and show one of the major reasons for using siren facilities. Correspondingly there is a major reason for using proof test facilities and that is -- that there is no satisfactory theory that will allow the accurate prediction of the fatigue life of a structure in a random noise field by means of data taken from siren tests (or tests that do not exactly reproduce the operating environment of the structure) so that configurations developed by analysis, by analysis plus design tests, or simply by comparative design tests must be verified by proof tests.

The balance in testing is the usual one of cost versus accuracy of results. At

one end of the spectrum is design testing of simple specimens with a discrete frequency siren (\$25 to \$100 per hour) and at the other end of the spectrum the full scale testing of an entire vehicle (the Boeing half-wing facility, for example, costs \$30,000 per hour to operate).

Since to use only a design approach is to forsake reliability and to use only a proof testing approach is to waste money, most vehicle development programs use both design and proof testing in one form or another. For example, preliminary designs might be established in an accelerated siren test, intermediate designs established on a jet engine test stand, and the final design verified by ground run-up tests on the actual aircraft (this is the kind of procedure followed by Convair, Fort Worth on the B-58 program). How the design and the proof testing approaches are mixed will determine the cost and reliability of a given sonic fatigue program, and is something that varies from company to company.

It must be recognized that this somewhat black and white dichotomy can not always be made and that a test may possibly have the characteristics of both design and proof testing. For example, a proof test may be of such an arbitrary nature and involve so many assumptions regarding the sound field that it may be little better than a comparison test. By and large, however, knowing whether a noise source or installation is used for one or another of these purposes is useful in establishing the context in which it should be evaluated.

Not many general remarks can be made about a facility used for research and development other than that it should be capable of producing the noise fields and the structural responses that are to be studied in the various research programs and that sufficient equipment must be available to make necessary measurements. Whether jet engines, air jets, random sirens or discrete frequency sirens are used, depends to a large extent on the type of work planned. Work on the correlation of jet engine noise fields cannot be carried out in siren facilities, whereas the development and checking of analytical tools may require such precise knowledge and control of a noise field as could only be obtained in a carefully designed siren facility. The evaluation of a

research facility must be made in terms of how successfully it can do its job and also whether the job can be done cheaper by other means.

IV B. THEORETICAL BACKGROUND OF SONIC FATIGUE WORK

In order to understand and evaluate what is done in the various test facilities it is important to know the theoretical background from which the testing derives and to understand the currently accepted description of the random fatigue process. Perhaps the words "currently acceptable" implies more general agreement as to theory than actually exists, for many features of the random fatigue process are still the subject of disagreement among authorities in the field; where there is major disagreement, however, we shall try to delineate that fact.

IV B-1. General Description of the Random Fatigue Process

The exterior surface of a flight vehicle is exposed to a pressure field which fluctuates randomly in time and space; the source of this pressure field is the complex sound field radiated from the jet efflux and the pressure fluctuations in the turbulent boundary layer. The elastic surface of the vehicle responds dynamically to this oscillating load and undergoes flexural vibrations with attendant flexural stresses which eventually lead to fatigue failure.

To describe the behavior of an elastic surface (such as a panel) under a broad band excitation it is best to start with Miles' discussion of the statistical nature of the response of a single-degree-of-freedom system. If lightly damped, such a device will act as a narrow band filter whose response will be large in its resonance band but low at all other frequencies. The dominant response will thus be due to all frequencies lying in this band, i. e. it will be the superposition of a number of signals whose frequencies lie very close to one another. Referring to the phenomenon of beating which occurs when two slightly different frequencies act in unison, and extending this to a number of frequencies, it is then argued that the response of the system will be in the form of an

approximately constant frequency (corresponding to the resonant frequency) with an envelope that will vary in a random manner. Miles developed the statistical properties of this envelope and showed that it has a Rayleigh probability distribution.

The extension of Miles' methods to the random excitation of a continuous, two-dimensional structure has been carried out and may be approached conceptually as follows:

If we consider the panel divided into an array of elementary areas, each of which sustains a pressure corresponding to the local random pressure, it can be seen that each elementary area will tend to select different frequencies from the excitation. Thus, if the area under consideration lies close to a point which corresponds to a node (in the panel) for a given frequency, the area will tend to reject that frequency. If, on the other hand, it is close to an anti-node it will tend to accept the corresponding frequency.

While the proximity of a point to a node or an anti-node influences the acceptability of a frequency by that point, there is another property which enables the point to discriminate against a signal. For example, two points might be ideally situated to accept (individually) a given frequency - i. e. they are located at anti-nodes - yet they need not accept the signal in unison. If, in the mode for which these two points are anti-nodes, the modal pattern requires the two points to move in opposite directions (i. e. out of phase) it is to be expected that this will cause some sort of discrimination against the applied signal. This discrimination is essentially a spatial characteristic and senses the interaction of wavelengths of the impinging sound field with wavelengths of flexural waves in the surface. It is expressed in terms of the 'joint acceptance' property of the structure which in turn is a function of the spatial correlation in the sound field and the modal characteristics of the structure.

Thus we see that the response of a distributed system is controlled by three factors, (a) the spectral distribution of the power in the excitation, (b) the 'time-sensitive' filtering action exercised by the natural frequencies of the structure, and (c) the 'space-sensitive' filtering action exercised by the flexural wavelengths in the structure.

These factors can be used as a basis for the analytical prediction of the stresses excited in a structure by a random loading (the stresses are usually quoted in statistical terms, either as a root-mean-square value or in terms of the probability of exceeding a given stress level).

The next step in building up a description of the random fatigue process is to associate these stresses with damage in the material and to devise a method of estimating the rate of accumulation of this damage. It is at this point that the greatest divergence exists between the various authorities in the field of fatigue, and various theories can be used.

There are two different (but complementary) approaches to the question of damage. The first of these seeks, by careful observation of the crystal structure of a specimen, to detect and measure microscopic changes occurring during fatigue. By categorizing the different manifestations of damage (heat generation, slip band formation, crack initiation, crack propagation, etc.) it is hoped to build up a satisfactory picture of the accumulation process which can then be used as the basis of a quantitative description. This approach, while it will eventually lead to a firm foundation for a fatigue theory, yields results slowly.

The second approach attempts to circumvent the need for an understanding of the microscopic process by postulating an abstract or idealized picture of damage initiation and/or accumulation and developing the logical consequences of this in terms of a number of adjustable parameters. These parameters are then adjusted to bring the theory into agreement with actual measurements of fatigue life. As two examples of this approach we might mention Freudenthal's statistical theory based on the probability of disruption of atomic bands and Dolan's concept of damage nuclei whose growth is related to the number of cycles by a power law (see Section IV B 3.).

The fact that damage initiation and accumulation are imperfectly understood has led to a situation in which there are almost as many hypotheses as there are workers in the field. Indeed, the increased interest in the fatigue phenomenon brought about by

sonically induced failures has significantly expanded the number of theories of accumulation. The unfortunate part of this is that most of these theories can be made to agree with experimental data for some condition of loading, but none is apparently capable of embracing all conditions of fatigue loading.

The main difficulty is the random nature of the stress-time history. In the more conventional experiments on fatigue a specimen is subjected to an alternating stress which varies sinusoidally about some mean (which may be zero). The three important quantities in the test are then the mean stress, the amplitude of variation, and the number of cycles to failure. In a purely random stress-time history the important quantities are not obvious and varying significance has been attached to the arithmetic mean stress, the root-mean-square stress, the probability of exceeding a given stress level and the distribution of peak stresses, the average number of zero crossings per unit time, and the time to failure. The different theories of accumulation have various ways of incorporating these statistical variables and these are discussed later in this report.

If a satisfactory analytical description of the accumulation process were available, the final step in the prediction of fatigue life would be a measurement of the capacity for damage possessed by a given material. This is currently measured in terms of the number of cycles of a sinusoidal stress of given amplitude which will cause failure, and is quoted in the form of an 'S-N curve' (stress level versus number of cycles). Data obtained from such tests exhibit considerable scatter and the S-N curve is an average of these data.

A different (and in many ways more satisfying) approach is advocated by Freudenthal, viz: if a family of specimens is tested at a given stress level S , then any number of cycles N has associated with it a probability of survival within the family. The damage capacity of a material is then quoted in the form of a three-dimensional plot of stress-versus-cycles-versus-probability of survival. S-N curves can still be drawn but now each one refers to a given probability of survival.

From the comments made in this section it can be seen that there are four

important aspects of sonic fatigue testing. These are:

- (1) Excitation of the structure or specimen,
- (2) Response of the structure or specimen,
- (3) The rate of accumulation of damage associated with this response,
- (4) The damage capacity of a material.

IV B-2. Sonic Fatigue Design Procedures

In design facilities the procedures or theories that are used to develop structures to withstand operational sonic environments from test data taken with sirens (or other noise sources) is of central importance. Even in proof testing facilities, to the extent that the test deviates from operational conditions, the theories that relate the test to the service environment are important.

Of the fifteen facilities visited and discussed in Section III, five base their design techniques on the linear accumulation of cycle ratios — i. e., on what is generally referred to as Miner's rule. Others either use their own theory of accumulation or conduct tests in such a way that they can dispense with a theory of accumulation — say by setting an arbitrary goal for the life of a part under test.

These methods were outlined in the facility descriptions but as a matter of convenience we shall repeat them here for those installations that have a formal method of analysis.

Since Miner's rule is used in Miles analysis (the starting point of many of the procedures) as well as in most of the methods to be discussed, it is useful to describe the rule.

Miner's Rule as it appears in Miles' Formulation:

If a specimen sustains a stress of amplitude S for a number of cycles n and the fatigue life at that stress is N cycles, then, it is postulated that the fraction of permissible or total damage sustained during the n cycles is $\frac{n}{N}$. If the stress amplitude takes on a number of different values S_i ($i = 1, 2, \dots$) with a corresponding number of

cycles to failure N_i at each level, then the damage is considered to accumulate linearly and the fraction of total damage is $\frac{\sum N_i}{N_i}$. At failure then $\sum \frac{N_i}{N_i} = 1$.

In Miles' formulation the response of a simple, damped, mechanical oscillator excited by a random load is shown to be a modulated carrier whose envelope fluctuates in a random manner. Further, successive maxima and minima of the carrier differ by a fraction which is of the same order as the damping ratio δ . Since this is small for a lightly-damped oscillator, the system may be considered to sustain approximately completely reversed loading and the idea of fatigue 'cycles-to-failure' is appropriate. The probability distribution of the envelope is shown to be described by the Rayleigh density function, so that the probability that a given stress peak lies in the small range $d\sigma$ is $P(\sigma) \cdot d\sigma$ where $P(\sigma)$ is the Rayleigh function.

Thus, for a number of stress-cycles-to-failure N , the number which lie in the small range is $[N \cdot P(\sigma) \cdot d\sigma]$ and the fractional damage contributed by these is $\frac{N \cdot [P(\sigma) \cdot d\sigma]}{n(\sigma)}$ where $n(\sigma)$ is a function describing the conventional (constant-amplitude) stress versus cycles-to-failure behavior, i. e. the orthodox S-N property. Consequently, for failure to occur in N cycles

$$\int_0^{\infty} N \cdot \frac{P(\sigma)}{n(\sigma)} \cdot d\sigma = 1$$

or

$$N = \frac{1}{\int_0^{\infty} \frac{P(\sigma)}{n(\sigma)} \cdot d\sigma}$$

Now N can be considered as the number of cycles corresponding to a reduced or equivalent stress σ' i. e. $N = n(\sigma')$, so that, if the form of $n(\sigma)$ is known, the above integration can be obtained explicitly and either N or σ' can be found. Miles assumed a simple logarithmic relation for the S-N curve and carried out the integration. A parameter which appears in the probability density and which varies from case to case

is the mean square response and this Miles expressed in terms of the dynamical properties of the oscillator and the power spectral density of the excitation. Thus, the expected life or the equivalent constant-amplitude stress for a simple structure under random loading can be found.

Boeing Airplane Company (Seattle Division)

Since this Division does not have a routine procedure for sonic fatigue testing each problem is treated individually and there is no routine method of data processing.

Hitherto, it has been usual to base the interpretation of data and the prediction of fatigue life on Miner's linear accumulation hypothesis, but recently an alternative method of estimating damage accumulation and predicting fatigue life has been proposed by J. R. Fuller.

As an example of the prediction of a service failure based on Miner's hypothesis, we will consider the case of the sonic fatigue of fuselage skin panels in the KC-135 aircraft.

There were indications that this aircraft suffered some fatigue cracking in the aft body after approximately 3 hours of maximum wet power during ground sonic testing. To counteract this, circumferential straps were added, and the predicted effect on fatigue life was determined in the following way:

The rms stress and the statistical distribution of the peak stresses were found from strain gage recordings obtained for the critical location on the 'basic' or 'unstrapped' aircraft when the engines were being run at maximum wet power. The stress range obtained from the strain records was then divided into 20 intervals, and the number of stress peaks occurring in each interval during a 1-hour period was found from the distribution and the average number of peaks on a 4-second record. Since the critical rms stress (at the point where failure eventually occurred) was unknown because the strains were measured adjacent to a row of skin-stringer spotwelds, the next step was to assume some ratio between the actual rms stress at the edge of a spotweld and the measured rms stress. This

ratio was used to 'adjust' the previous stress intervals, thereby obtaining a tentative distribution of stresses at the location of eventual failure. Using the number of stress peaks in an adjusted interval and the corresponding cycles to failure from an appropriate S-N curve, (sinusoidal) the incremental damage associated with each stress interval (for a 1-hour period) was found from Miner's cycle ratio $\frac{n_i}{N_i}$. By summing this over all the stress intervals, the hourly accumulation of damage was found and the reciprocal of this gave the life in hours.

Repeating this for a number of assumed ratios of critical stress to measured stress allowed the correct 'adjusted' rms stress (one that would give the 3-hour measured life) to be found.

This procedure was repeated using the same strain gages after the circumferential straps were applied to the airplane and the same ratio was used to adjust the measured rms stress thereby yielding a prediction of the improved life resulting from the strapping.

A technique for estimating service life of an aircraft was developed in a study of structural fatigue of the B-52 series of aircraft (B-52B through B-52G). It is based on an approach which is fundamentally the same as that used in the study of the KC-135 but assumes a Rayleigh distribution of peak stresses rather than an experimentally determined distribution. The technique uses a mission profile covering a typical year of operation of the aircraft. This mission profile takes the average annual flight time and breaks this down into periods at different engine powers, each period is then associated with a different sound pressure and hence an rms stress level. The connection between engine power, sound pressure, and stress is established experimentally. Assuming a Rayleigh distribution of stress peaks and referring to an orthodox S-N curve, the cumulative damage (as defined by Miner's summation of cycle ratios) for each period is found. From this the annual damage rate is found and thence the estimated service life of the aircraft.

Recently, J. R. Fuller devised a method for estimating fatigue life under

variable-amplitude cyclic loading which does not use Miner's hypothesis. The method is based on the premise that if a specimen is cycled under some variable load pattern between two limiting over stresses, the greater of which is S_A and the smaller S_a , then failure may be expected to occur at some number of cycles greater than that which would cause failure by cycling at S_A alone and less than that which would cause failure by cycling only at S_a . The interpolation of the actual variable-amplitude life between these two limiting lives is carried out by means of the formula

$$N_v = N_a \left(\frac{N_A}{N_a} \right)^\beta$$

where N_A and N_a are the fatigue lives at the upper and lower stress levels respectively and the exponent β reflects the distribution of stress levels between the upper and lower limits. The value of β is found by plotting the distribution of stresses in 1000 cycles on a semi-log grid and taking the ratio of the area under the curve to the area of the grid.

The method is empirical and proceeds from consideration of the differing geometries of the fatigue-life curve under constant-amplitude loading and variable-cycle loading.

Methods used by Convair (Fort Worth Division)

Data interpretation at Convair, Fort Worth is based on Miles' treatment of the response of a single-degree-of-freedom linear oscillator. Several minor modifications to Miles analysis are made, e. g. (a) modifications introduced by Regier and Hubbard to relate mean square stress to panel dimensions and (b) the incorporation of a multi-mode response factor as recommended by Powell and which is the ratio of the total mean square stress response of all significant modes to the mean square stress response for the test mode under consideration.

Random fatigue curves have been used, but no detailed information is available on the methods of constructing these curves.

The principal use of Miles' results appears to be in the selection of a

single-frequency test-level suitable for an accelerated (siren) test. The test-level is chosen so that a 3-hour siren life is equivalent to 10 hours of life at the noise level produced by ground operation with afterburner.

Using Miles' expression relating rms stress to the power spectral density of the excitation it is possible to select a siren sound pressure level which would produce the same rms stress. This is adjusted by two factors; the first of which is the multi-mode factor previously mentioned. The second factor is a 'peak stress factor' and is introduced as follows: from a frequency sweep of the test structure, the frequency of maximum response is determined and from this the number of cycles corresponding to 10 hours of life is found. From constant amplitude and random S-N curves two stress levels are found corresponding to this life, the ratio of these levels is the 'peak stress factor' and it is used to calculate an SPL that will produce a siren test life which is equal to the service life (N_L cycles to failure). This is the unaccelerated life which is then adjusted to give the desired 3-hour siren life (N_T cycles to failure). Using the constant amplitude S-N curve and the number of cycles corresponding to 3 hours a new stress level is found; the resulting stress increase can be converted to pressure level increase by reference to an experimentally determined relation between pressure and stress. An additional pressure increase is usually incorporated as a safety factor and is arrived at by doubling the number of cycles N_L to give N_M and finding the corresponding stress interval between the lives N_T and N_M . This stress interval is converted to a pressure change which is then added to the test pressure.

Method used by Convair (San Diego)

The main purpose of the test program at Convair is to proof-test new designs. The evaluation procedure that is used may be separated into the following broad phases:

1. A statistical analysis is made of the jet acoustic pressure data at the station of interest.
2. The least damped resonant mode and corresponding frequency of the test panel is determined.

3. A test acoustic pressure based on relative slopes of applicable probability curves of jet pressure and stress cycle curve for a structural configuration of a test panel is determined.
4. The panel is tested to failure (or 15 hours) at the selected acoustic pressure and frequency.
5. The failure is interpreted in terms of random acoustic excitation provided by the jet.

The techniques used are based on experimental determinations of the probability distribution of peak pressure in a jet-engine field and on typical (constant-amplitude) S-N data.

One application of this information is in the establishment of a discrete frequency test in lieu of random testing, this is accomplished as follows:

By scanning a tape recording of near field pressures around a jet engine, measurements are made of the percentage of time during which various pressure levels are exceeded; this information is presented in terms of a graph relating the ratio peak/rms pressure to the probability of exceeding this pressure ratio. This curve is then replotted in terms of peak pressure versus the number of hours in the desired life of a structure during which a peak pressure is exceeded. The conversion is carried out by re-scaling the probability axis in terms of hours to failure by allowing 100% of the time to equal the desired life (e.g. 10,000 hours) and by re-scaling the pressure ratio axis to refer to some rms pressure (e.g. 148 db).

The orthodox, constant-amplitude S-N property of the structure is now taken as a straight line which is tangent to the previously constructed curve, and the point of tangency is used to define a critical pressure. This critical pressure is taken as that "which will most likely cause a structural failure". The area under the probability curve is now divided by the critical pressure yielding a value of 'hours to failure' and the critical pressure point is translated to this new abscissa. Through the point thus obtained a new line is drawn parallel to the original "normalized S-N curve". A structural failure at any point on this curve under sinusoidal excitation is considered

equivalent to a failure at the number of hours chosen for the life (e.g. 10,000 hours) under random excitation at the chosen rms level (e. g. 148 db).

The construction of these curves is illustrated in Figure IV B-1 which is taken from Convair Memorandum Report DG-G-183.

The following type of information is presented by Convair to summarize siren test results.

1. Frequency surveys of the strain gages, strain versus frequency.
2. A description of the panel and its mounting configuration showing strain gage locations.
3. A strain versus sound pressure plot of the various strain gages.
4. The level at which the test is conducted.
5. The number of hours to failure and the frequency at which the test was made.

At the present time, the data is reduced manually.

Methods used by Douglas Aircraft Company (Santa Monica Division)

The data reduction techniques and the method of selecting siren test levels are based on an extended form of Miles' analysis developed by VanDyke, Belcher, and Eshleman.

As in Miles' work, the response of a panel is described in terms of a randomly modulated carrier whose envelope has a probability density in the form of a Rayleigh distribution. The carrier frequency corresponds to the first resonance of the test panel.

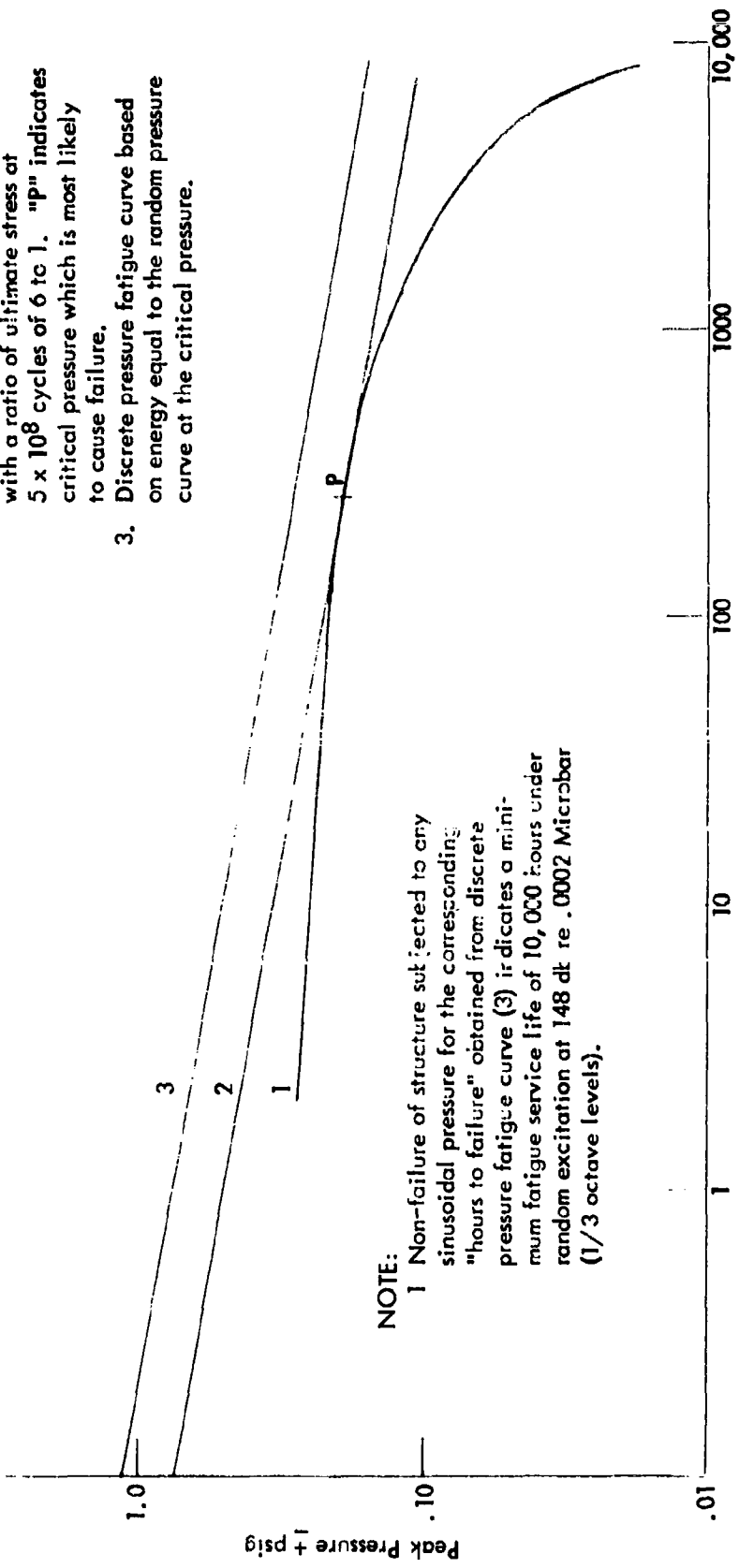
Since the probability distribution of stresses is the same for each test, the index of severity of an individual test is the rms stress — the most probable stress. Using the rms stress as the index of stress intensity it is then possible to develop an 'S-N' curve for random loading. This is done by relating the random fatigue life N and the orthodox S-N data in terms of the Rayleigh density function as was described at the beginning of this section.

As already stated, this relation is in terms of an integral which contains two stress dependent quantities; to accomplish this integration, Miles assumed that stress

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LEGEND:

- CURVE
1. Cumulation of peak pressure hours in 10,000 hours for C-J-805 engine.
 2. Fatigue curve based on an S-N curve with a ratio of ultimate stress at 5×10^8 cycles of 6 to 1. "p" indicates critical pressure which is most likely to cause failure.
 3. Discrete pressure fatigue curve based on energy equal to the random pressure curve at the critical pressure.



Hours to Failure

CONVAIR, SAN DIEGO

ENVIRONMENTAL ACOUSTIC PRESSURE VS. HOURS TO FAILURE

FIGURE IV B-1

and cycles-to-failure in the constant-stress-amplitude fatigue test are related by a simple power law. In the method developed by Douglas the integration is carried out numerically using experimental S-N data.

At this point it is possible to construct a 'random loading S-N curve' in which the stress level is the rms stress. A further S-N curve can be drawn in which the stress referred to is the "peak-damage stress". The concept of a peak-damage stress arises as follows: - high stresses contribute strongly to damage but they occur relatively infrequently, lower stresses contribute less strongly but they occur more frequently, consequently there is an intermediate stress level at which the damaging ability and the frequency of occurrence unite to produce the "peak-damage stress".

Since the damage contributed by a stress level S_i is $\frac{P_i}{N_i}$ the fractional damage is $\frac{P_i}{N_i}$; the value of stress for which this reaches a maximum is the peak damage stress.

Having constructed a random loading S-N curve, the next step is to predict the rms stress which will be experienced by a panel in its service environment. This is done by using Miles' formulation of the response of a single-degree-of-freedom linear system in terms of its resonance frequency, damping ratio, power spectral density of the excitation pressure in the resonance band, and stress response to a unit static load. Miles' formulation is extended by the inclusion of two factors one of which provides for the excitation of more than one mode in a test panel while the other is a correction to account for non-linearity of the 'stress response versus load' curve.

The analytical methods outlined above form the rational basis of the siren testing carried out by Douglas. Siren tests are primarily of two types, the first of these being frequency response explorations of a structure yielding data on resonance frequencies, damping factors, relative stress magnitudes, and stress-versus-load curves. These data are then used to compute multi-mode and non-linearity correction factors which can then be incorporated in the formal computation of the expected life in a given service environment. The actual computation is best accomplished by a very convenient nomograph

entitled "Fatigue Life Design Chart-Random Loading" which is used to predict the allowable noise level for a given life. Rather than reproduce the nomograph exactly, its form and use will be described in general terms.

A 3-cycle by 5-cycle log-log grid is divided into six areas each of which introduces a different term into the 'computation', these terms are: dynamic amplification factor, stress concentration factor, sound pressure level, static stress, random S-N property, and service life. The first and last named areas (the 'beginning and end' of the nomograph) are provided with frequency scales, while each area contains a series of lines corresponding to different values of the appropriate factor. In the prediction of allowable noise level one enters the nomograph simultaneously at each end (using the resonant frequency of the panel) and proceeds from zone to zone using the appropriate value of the corresponding factor until the paths intersect in the zone of sound pressure level where the allowable level is read off.

The second type of siren test is an accelerated test in which a short term (20-30 minutes) exposure to a relatively high noise level is used to measure or verify the expected life of the panel in its simulated service environment (jet engine test).

For this work a second nomograph has been constructed, entitled "Conversion Chart: Discrete Loading to Random Loading". Once again a six-zone nomograph is used, the factors introduced in the various zones being damping ratio, non-linearity, ratio of test noise-level to service noise-level (db difference) test life, service life, and multi-mode correction factor.

As before, the nomograph is entered simultaneously at each end (using the resonance frequency of the panel) and the paths intersect in the zone of noise-level ratio, thus yielding the test level for given conditions of service level and service life and an arbitrarily chosen test life.

A variation of this method of accelerated testing is used in which the panel is exposed for a series of short periods (say 15 minutes at each major mode) to different levels until failure occurs; these levels increase in 3 db steps. The number of cycles of exposure at each level is known but the actual critical stress in the panel at each

level is not known. However, the ratios of the different stress levels are known from strain gage readings. If a first approximation to one stress level is assumed, then all other stress levels are known; next, the fatigue life at each level can be found from an S-N curve, consequently the cumulative damage at each level is known (ratio of actual cycles to life) and the sum of these should be unity. A series of trials gives the proper value of stress level to yield a cumulative damage of unity. This then gives the correct relation between critical stress and (strain gage) indicated stress.

An arbitrary choice of critical stress (and its corresponding life) for a single-level test can then be converted to a corresponding measured stress. From an experimental stress/load curve the appropriate test level can be found and the nomograph can be used to find an allowable service load for a desired service life.

Methods used by the McDonnell Aircraft Company

McDonnell has used a random S-N curve relating rms stress to cycles-to-failure, and the construction of this curve proceeds along the lines of the Miles analysis using the linear accumulation hypothesis. As in other cases, the integration appearing in the analysis is based on experimental (conventional) S-N data and is accomplished numerically. The rms stress experienced by a panel in the service environment is calculated by the Miles method from the power spectral density of the excitation and the following procedure is employed to estimate this property of the excitation.

From curves of the sound field around a representative engine (J-57) operating at a jet velocity of 1850 ft/sec., the sound level at the location of the panel is estimated. This first estimate is corrected to the expected operating condition of the service engine by using the fact that the sound level varies as the n th power of the velocity — empirical values of the exponent n are used. This corrected value is then increased by 4.5 db to allow for effects due to ground reflection. If there is more than one engine, this process is repeated to find the total of contributions to the sound pressure on the panel. This, of course, is the overall sound pressure and it is now required to find the power spectral density of this excitation in the frequency band corresponding to resonance in the

structure. It is found that the power spectrum of a jet engine noise field has a reasonably constant shape when plotted in terms of Strouhal number rather than frequency (Strouhal number = frequency X jet diameter/bulk velocity). Using this fact, and calculating panel frequency by means of a nomograph, the spectral density in the resonance band is found. As already stated, this information enables the rms panel stress to be computed; this, in turn, allows the fatigue life to be read off from the random S-N curve.

Method used by the Martin Company (Baltimore Division)

Most of their SF work has been in connection with the P6M program and has consisted of the following four general steps.

- (a) The determination of the sound intensities on the P6M hull by means of measurements made along a hull structure during operation of the jet engines.
- (b) The comparison of the life of various modifications to the hull structure by means of siren tests on small panels representing the hull structure.
- (c) Exposure of test panels to the jet and siren noise field to determine the type and magnitude of response in order to establish a relationship between the time to failure in siren tests and the time to failure in the jet noise field.
- (d) Verification of noise and stress intensities on and in the actual aircraft by measurements during flight and ground testing.

The results of the panel tests using the siren were tabulated on summary sheets which included; panel number, time to failure, type of failure, panel description (dimensions, skin gage, type of frame, frame gage and spacing, and stabilizing member gage and spacing), frequency, and sound pressure level. Failure was defined as any visible crack in the basic structure. Approximately 150 panel configurations were tested and summarized. Throughout the testing program, various alterations were made to the panel types to improve their life.

The destructive testing carried out by discrete frequency sirens is related to

the service life in the operating environment in the following way.

A preliminary test in a jet noise field is made to obtain the dominant modal response and the rms stress produced by the random excitation. This test is followed by exposure to a high intensity siren operating at the resonant frequency (obtained from the jet engine test) and measurements are made of the rms stress. Siren excitation is continued at its maximum intensity until failure occurs.

The problem is now to relate the siren test life at the corresponding rms stress to a predicted random noise life at the appropriate rms stress. It is to be realized that the stresses quoted are not the 'critical' stresses at the location of ultimate failure but are 'reference' stresses measured at some convenient location — it would be simply fortuitous if the measured stress were the critical stress.

The next step is to obtain an orthodox (constant-amplitude) S-N curve and this is done by using a Sonntag driver to excite a specimen in reversed bending. This S-N curve can be quoted in terms of rms stress, or in dimensionless terms by dividing by the largest value of rms stress used in the test. The latter form, i. e. 'rms stress ratio' versus cycles to failure was the form used.

It is now possible to construct a 'random S-N curve' by using this conventional fatigue data in conjunction with the Rayleigh distribution of peak stresses to obtain damage increments which are then summed. This summation was carried out by Miles as an explicit integration but was accomplished by Martin in the following way. The abscissa of the Rayleigh distribution was divided into a number of stress ranges by suitable ordinates and the area bounded by each pair of ordinates and the curve was found. The product of this number and the total number of cycles gave the number of cycles in the test life which lay in this range. When this was divided by the conventional fatigue life for this stress level the result was the incremental damage. The sum of the damage increments was taken to be .33 rather than unity which is the value usually taken when employing the linear accumulation hypothesis of Miner.

At this point there is available

(1) Hours of life in the siren test

(2) An orthodox S-N curve

(3) The ratio of stress produced by the siren to stress produced by the jet

(4) A random S-N curve

Using (1) with (2) yields an effective siren stress which, by using (3) can be converted to an effective jet stress; this last can be used with (4) to obtain an expected jet life.

Methods used by the Martin Company (Denver Division)

Although this division does essentially proof testing on missiles with random and discrete frequency sirens and, therefore, does not use theories of fatigue prediction as we have been describing them, they do have a method of determining the test sound pressure levels. This is necessary since the conditions of the test are not the same as the operational environment.

In fatigue tests of missile structures, segments of the structure are tested with localized high-level random acoustic excitation. This test condition is not the same as would exist in a silo where the entire missile (or a good part of it) is exposed to the noise, and the test SPL must be adjusted to account for this fact. The test level is arrived at in the following way:

If the missile structure is considered to be made up of n segments or regions all subjected to the same pressure level p when in the silo, then the response (rms) in the r^{th} region due to this pressure in the s^{th} region is A_{rs} where A_{rs} is an influence coefficient relating pressure and response (as measured by, say, acceleration). These coefficients are found by measuring the response in the n regions when one region is excited (e. g. if region 1 is excited then measurements in the other regions give A_{11} , A_{21} ---- A_{n1}); it is assumed that reciprocal relations hold, i. e. $A_{rs} = A_{sr}$. If all regions are excited simultaneously by the same pressure p then contributions to the response in say region 1 are $A_{11} p$, $A_{12} p$, ---- $A_{1n} p$ but by the reciprocal relation these are $A_{11} p$, $A_{21} p$, ---- $A_{n1} p$ and these coefficients have already been found.

Assuming the net rms response in region 1 to be the square root of the sum of the squares of the various contributions gives

$$P \sqrt{(A_{11})^2 + (A_{21})^2 + \dots + (A_{n1})^2} = P \sqrt{\sum_k (A_{k1})^2}$$

If a test level P applied to region 1 alone is to produce the same response, then $A_{11}P$ must equal

$$P \sqrt{\sum_k (A_{k1})^2} \quad \text{or } P = p \frac{\sqrt{\sum_k (A_{k1})^2}}{A_{11}}$$

hence,

$$db \text{ (localized test)} = db \text{ (silo)} + 20 \log_{10} \frac{\sqrt{\sum_k (A_{k1})^2}}{A_{11}}$$

This test pressure is applied to a localized region for a period of 10 minutes and will produce the same local damage as would 10 minutes exposure in the silo.

IV B-3. Cumulative Damage Theories

While it is not the purpose of the present report to consider all the damage accumulation theories that have ever been proposed, it is worthwhile to make a brief mention of some of these simply to show their number and range, and to show how they differ from Miner's theory which has been described.

Shanley's Method

Shanley bases his method on the unloading of atoms due to reversed slip on the same plane. He assumes that every cycle of applied stress above the fatigue limit contributes to damage and that damage is synonymous with crack growth.

If the conventional S-N curve is represented by $N = a (\sigma - \sigma_e)^{-\beta}$ where σ_e is the endurance limit, then a reduced stress σ_r is defined by the relation

$$\sigma_r^\beta \sum_i n_i = \sum_i n_i \sigma_i^\beta$$

In this σ_i is the stress level which is experienced n_i times during the total life of $N (= \sum n_i)$ cycles.

Henry's Method

Fatigue damage is here defined as a reduction in endurance limit caused by a hypothetical increased local stress concentration produced when a stress above the endurance limit occurs. The conventional S-N curve is represented by $N = K (\sigma - \sigma_e)^{-1}$ where K is a stress concentration factor. The damage produced by n cycles of the stress σ is defined as

$$D = \frac{\sigma - \sigma_e}{\sigma_e} = \frac{n/N}{1 + \left(\frac{\sigma - \sigma_e}{\sigma_e}\right) \left(1 - \frac{n}{N}\right)}$$

In this way damage is associated with the cycle ratio n/N corresponding to an applied stress σ .

When considering the effect of more than one stress level, specifically the type of loading known as 'block' loading (i.e. successive 'blocks' of equal stresses but each block with a different value), the damage after the occurrence of a number of cycles at one stress level is redefined in terms of the equivalent cycle ratio for the next stress level. This equivalent cycle ratio is given as

$$\left(\frac{n}{N}\right)_i = \frac{D_{i-1} \left(1 + \frac{\sigma_i - \sigma_e}{\sigma_e}\right)}{D_{i-1} + \frac{\sigma_i - \sigma_e}{\sigma_e}}$$

D_{i-1} is the damage at the end of the $(i-1)^{th}$ cycling.

Corten and Dolan

This method assumes that damage can be expressed as

$$D = m r N^a$$

Where m is the number of damage nuclei and is considered to be a function of stress level, r (which is also a function of stress level) is a coefficient of the rate of damage propagation and N is the number of cycles. If the load history is characterized by two stress levels and N is the number of cycles to failure if the higher stress acted alone, then N_t (the total number of cycles when both levels are present) is given by

$$N_t = \frac{N}{\alpha + R^{1/\alpha}(1-\alpha)}$$

Where α is the ratio of the number of high-stress cycles to the number of low-stress cycles, and R is the ratio of r for the low stress to r for the high stress. This has been extended to cover any number of stress levels as follows:

$$N_t = \frac{N}{\alpha_1 + \alpha_2 \left(\frac{\sigma_2}{\sigma_1} \right)^d + \alpha_3 \left(\frac{\sigma_3}{\sigma_1} \right)^d + \dots + \alpha_i \left(\frac{\sigma_i}{\sigma_1} \right)^d}$$

In this expression N is the number of cycles to failure at the highest stress level, α_i is

the percentage of cycles occurring at the stress level σ_i . The term $\left(\frac{\sigma_i}{\sigma_1} \right)^d$ is used

because it was found empirically that $R^{1/\alpha} = \left(\frac{\sigma_i}{\sigma_1} \right)^d$

All of the above theories of accumulation have been given limited testing using fatigue measurements made with programmed loading. In each case the proposed rule satisfactorily fitted the test data for some loading spectra but was found unsatisfactory for others. In this respect, a current program at the Lockheed Aircraft Corporation (sponsored by WADD under Contract AF33(616)-6574) is concerned with the extensive testing of the different accumulation rules noted above. This program is not yet complete but the results should provide a more satisfactory basis than now exists for the choice of a suitable accumulation rule.

Tentative results based primarily on coupon test data indicate that Miner's

rule is as accurate as any of the other methods considered (the Beta Method recently suggested by Fuller at Boeing, Seattle was not considered by Lockheed). If this should be one of the final conclusions drawn in the program, it tends to justify the current use of this simple rule in predicting sonic fatigue life.

Work has recently been started by WADD to develop experimentally derived random fatigue curves (mainly to check cumulative damage theories). Such curves would be constructed from information gathered from specimens that had been subjected to random loads with some prescribed probability distribution. For example, the specimens could be subjected to bending stresses that had a Rayleigh distribution about each rms test stress. If random fatigue curves constructed from experimental data that simulate the statistical distribution of the operating environment are available, then a cumulative damage theory is not needed for the prediction of sonic fatigue life. Using experimentally constructed random fatigue curves is one way of avoiding the cumulative damage problem. Unfortunately equipment for producing such data is not readily available, and it is likely to be several years before curves for various materials will be available.

While the problem of cumulative damage still remains to be solved and while more accurate cumulative damage theories would be desirable, it should be recognized that there are many sources of uncertainty in the current methods of predicting sonic fatigue life and that an accurate damage theory or the existence of experimentally derived random fatigue curves does not solve the sonic fatigue prediction problem.

IV B-4. Discussion of Prediction Methods

One of the questions on our questionnaire was, "How do prediction methods compare with service life in actual environments?" The answers to this question could not be considered conclusive. Often no information was available; several of the companies (Convair, San Diego, Douglas, Santa Monica, Boeing, Seattle) reported that their method worked in the sense that structural configurations established by their method did not fail in operation; others (McDonnell) discussed how some siren tests compared with jet engine stand tests; there was not, however, a body of data that compared flight

vehicle performance with siren or jet engine performance. The bare fact that the various design methods will give a structure that does not fail in operation, while important, is only half the story since it offers no way of deciding whether the structure was over-designed. We have seen almost no documentation of the fact that the various methods "work", and while there is little reason to doubt the general truth of the statement, it must be recognized that it probably does not mean that every design made with a given method experienced no failure, but rather that a given aircraft had only minor or non-critical problems with sonic fatigue after it had been designed and proof tested.

Since the common procedure is to establish a structure by design testing and then proof test it, as long as the proof test is severe enough, the configuration should stand up in operation, and the value of the design procedure will hinge on the ease and speed with which a structure can be designed to pass the proof test. Whether or not a method has a clearly defined logic that rests on presently accepted engineering principles is also important and, other things being equal, such a method is to be preferred to one not so constructed. Most of the methods in current use assume Miner's rule and are based on Miles' analysis of the response of a single degree of freedom system to a random excitation. There are a few exceptions to this; Boeing, Seattle uses a jet engine to obtain the stress response and they also have an empirically determined damage accumulation rule, G. Getline at Convair, San Diego has his own experimentally derived methods. Boeing's accumulation rule has never been used in aircraft design and little can be said about it here. G. Getline's method, while it has reportedly been used with success in designing the Convair 880, is controversial and involves such assumptions as that the statistical distribution of peak stresses can be obtained directly from the applied pressure amplitude distribution, that the most damaging stress is the predominant one in determining the life, and that lower stresses make negligible reductions in the fatigue life.

The procedure followed by Douglas Aircraft is the most highly developed of the methods used. Very similar procedures are followed by Convair, Fort Worth but we use Douglas as an illustration because its procedures are more highly codified. It is a reasonably logical method that has provision for considering such things as non-linear

and multi-mode panel response, and while it is certainly not the final solution, it is the best currently available. At the present time, the correction factors applied for these two effects are very crude. The correction factor for the non-linear response of the panel at high siren test pressures is simply the fraction obtained by dividing the stress to load ratio that exists at the peak damage stress by the stress to load ratio that exists at the siren test load. The difference between the non-linear behavior of the panel during the siren test and its behavior at all the other stresses (the peak damage stress is only one of these — although an important one) that occur during the random jet excitation is neglected.

The correction for multi-mode effects involves the assumptions that the modes are completely uncoupled, that they are well separated in frequency, that the fatigue life is a function of the total stress induced by the various modes, and that this stress can be approximated by measuring the stress response to discrete frequency excitation for each mode and taking the square root of the sum of the squares of these values.

An analysis has been carried out for the response of a two-degree-of-freedom system; but, this analysis has not been used in design.

The description of this method in the ASME publication 59-AV-48* contains a long list of sources of error possible when applying the procedure, and since these items, for the most part, are applicable to any of the design methods in use, we can do no better than to repeat them here.

1. An error of 1 db in sound pressure measurement represents approximately 12% error in load.
2. If the siren excitation frequency is off resonance, a large non-conservative error in damage accumulation can occur.

* "A Procedure for Designing and Testing Aircraft Structure Loaded by Jet Engine Noise" by Eshelman, VanDyke and Belcher, ASME Paper 59-AV-48.

3. Damping factors depend on how they are measured.
4. The propagation direction of the sound relative to the panel in a siren test and in an airframe application is not, in general, the same.
5. Harmonics of the siren fundamental pressure wave may excite higher modes of the structure.
6. The non-linearity of the structure depends not only on the design but also on the quality of fabrication, which is variable among specimens; e. g., skins which are tightly stretched begin to diaphragm at lower pressures than do loose skins. This can have a large effect on the correction factor.
7. If there is more than one significant mode, additional effects which contribute to errors exist.
 - (a) It is not necessary to know the actual values of stress for each mode, but the relative stress amplitude must be known if the computed value of the multi-mode correction factor is to be meaningful.
 - (b) The possibility of obtaining misleading strain gage readings due to a non-zero geometric angle between the principal stresses must be considered.
 - (c) There is no certainty that the structural area which is critical when all modes are excited simultaneously (as by random noise) is the location of failure in the discrete frequency test.
 - (d) Coupling between modes, especially when there is little difference between the resonance frequencies, causes difficulties in measuring the damping factors and results in questionable interpretation of their physical meaning.
8. For a specified life, allowable stress varies as much as $\pm 15\%$ for a plain smooth specimen, and an additional variation of $\pm 15\%$ occurs for a notched specimen.

As can be seen from this list there are problems connected with designing aircraft to resist sonic fatigue by the use of discrete frequency siren tests. The method

can certainly be improved* but even in its present state and so long as the final structure is proof tested, this procedure offers a reasonably quick and economical way of arriving at a satisfactory structure.

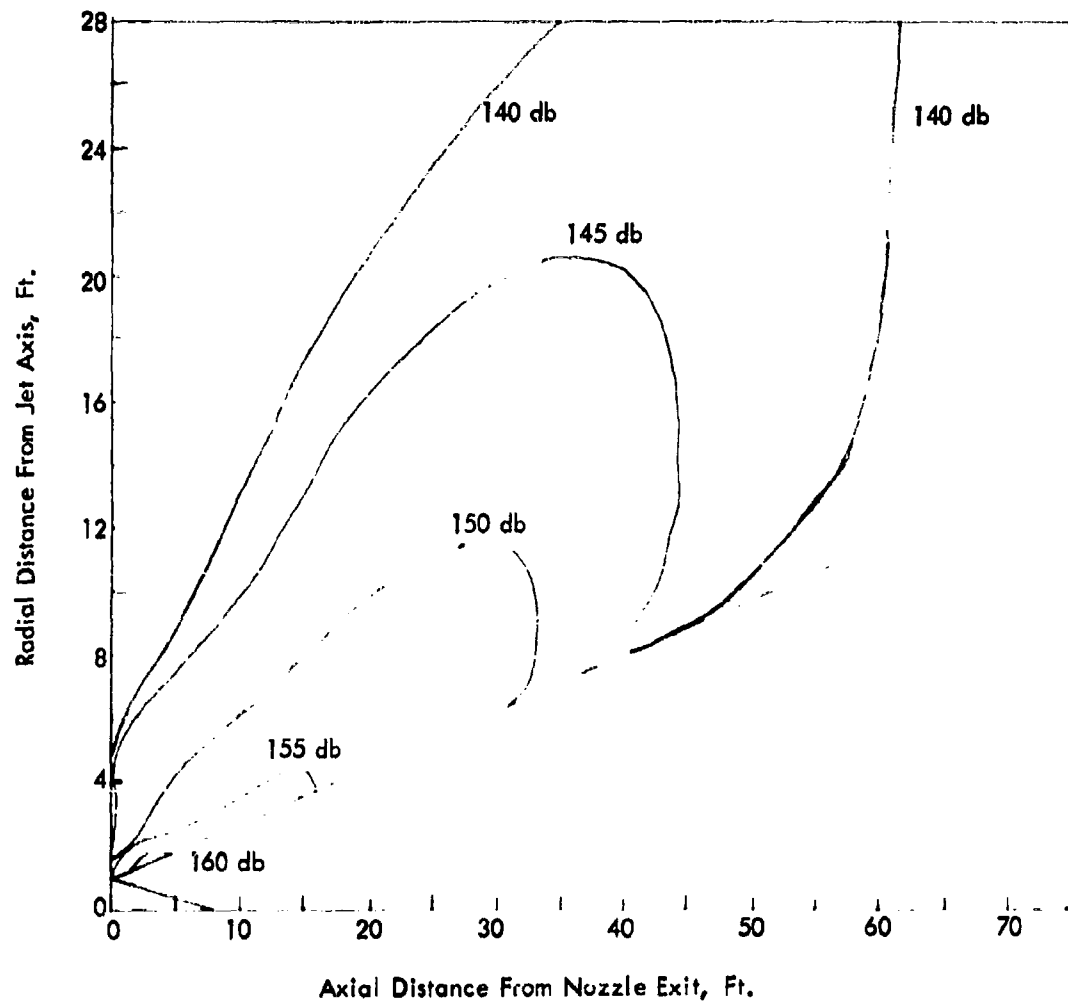
IV B-5. Spatial Correlation

Since most structures are loaded over a surface, the spatial characteristics of the sound field are of importance. The two aspects of the spatial properties that are of interest correspond very roughly to the amplitude and phase properties of a harmonic vibratory excitation, and we shall discuss first the "amplitude" characteristic and then the "phase" characteristic.

In measurements of the near field characteristics of a representative jet engine** of some 10,000 lb thrust, the sound pressure level ranged from 160 to 140 db over a distance of some 32 nozzle diameters (60 ft.) downstream and a distance of some 14 nozzle diameters (26 ft.) to the side — see Figure IV B-2. As can be seen, the sound field is directive with maximum propagation along a direction inclined between 30° to 40° to the jet axis. Along this direction the overall sound pressure level dropped approximately 5 db every 18 ft; along a direction close to the jet boundary this decreased to 5 db every 13 ft, and along a direction steeply inclined to the jet axis an even more

*In Section IV H we discuss the difficulties of measuring or obtaining many of the quantities such as rms stress or damping factors that are necessary in design.

**Howes, Callaghan, Coles, and Mull, "Near Noise Field of a Jet Engine Exhaust", 1957, NACA Report 1338



JET ENGINE SOUND CONTOUR LEVELS

FIGURE IV B-2

rapid variation is observed. While it is recognized that pressures experienced by a surface placed in the field will be considerably higher than the free field values, the pressure variations over such a surface will be quite similar to the variations in the free field. Thus, large spanwise variations could be expected over wing panels situated close to the nozzle exit, while afterbody panels at some distance downstream would experience much smaller pressure variations.

Only those installations using an actual jet engine can reproduce the spatial variations in sound pressure level experienced by a given panel in a given location on the aircraft. However, this is only significant for a few panel locations (e. g. the wing panel mentioned above); for the major part of the afterbody structure it is justifiable to assume that the sound level is constant over panels three or four feet in extent. Most facilities can provide a sensibly constant sound pressure level over the area of the test panel but none, other than jet installations, can provide a variety of spatial distributions.

The second spatial property of the sound field — namely, that property corresponding to phase — is described by the correlation coefficient between the pressures at any two points in the field. The significance of this property can be described briefly as follows. If two plates having different lengths, widths, and thicknesses, are designed to have a common resonant frequency ω then each panel will be receptive to the same part of the excitation spectrum. If one considers the geometry of the mode corresponding to the resonance ω in each plate, then, since points separated by one wavelength will move in-phase while points separated by a half wave length move out-of-phase, the lengths between in-phase points (and out-of-phase points) can be quite different in the two plates. If the wave length in one plate corresponds to the distance (in the sound field) between pressures which tend to act in unison, then that plate will be the more highly excited. If the wave length corresponds to the distance between pressures which tend to be out-of-phase, the plate will be much less receptive to the excitation. Thus, while the natural frequency of the plate interacts with the spectrum of the sound field to exercise a time-sensitive filtering action, the mode shape interacts with the correlation

function to exercise a space-sensitive filtering action. This latter phenomenon has been expressed in the form of a 'joint acceptance' function which combines modal properties of the structure and the correlation properties of the excitation. *

Figure IV B-3 (a) and (b) is reproduced from NACA Report 1338 and shows the longitudinal variation of the correlation coefficient in a jet-noise field for various frequency bands. Figure IV B-3 (c) and (d) is a replot of this same data in which the abscissae have been converted to the wave length corresponding to each frequency (in air). While, at first glance, the correlation properties of the various frequency bands appear quite disparate, a definite similarity is revealed if the data are replotted in terms of the wave length corresponding to each frequency rather than in terms of nozzle diameters.

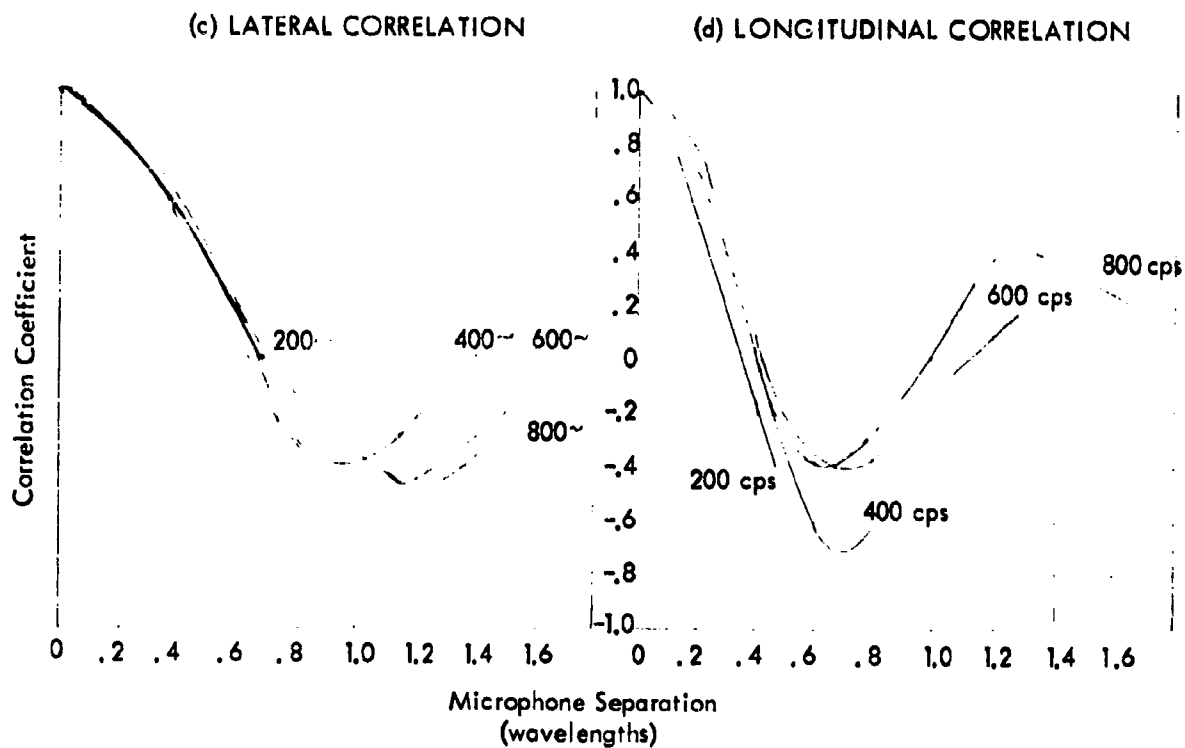
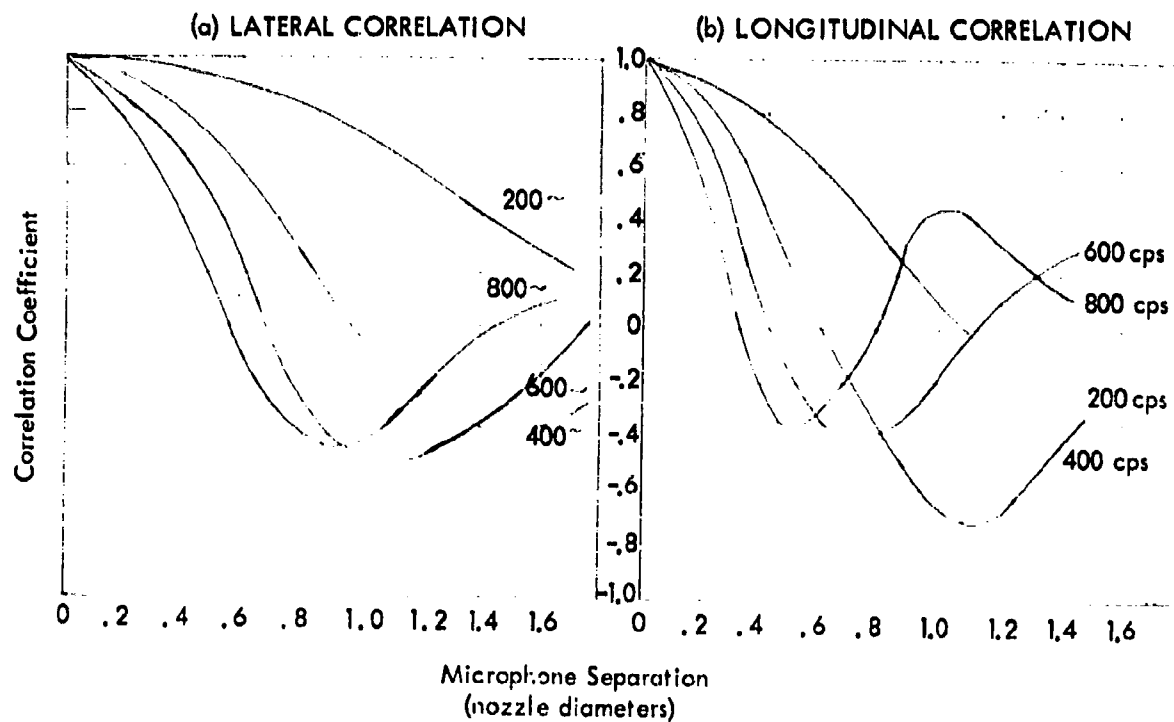
Up to the maximum negative correlation all frequencies tend to behave in the same way but there is a difference in the behavior of longitudinal and lateral correlations. Up to the first zero of the correlation the agreement is so good that it suggests that each frequency is behaving (over a short distance) like a simple propagating wave. However, a simple traveling wave would give a first zero of the correlation at a microphone separation of one quarter wave length, while the 'longitudinal zero' occurs at .4 wave lengths and the 'lateral zero' occurs at .65 wave lengths.

Now if one makes correlation measurements on a simple traveling wave, and the direction along which these measurements are made does not correspond to the axis of the wave, then the correlation behavior will be related to that along the wave axis by a sine (or cosine) relation. This suggests that the differing longitudinal and lateral correlations can be brought into agreement by comparing their behavior with the result of a train of simple waves whose axis is inclined to the jet axis.

Our aim is thus to find an angle (if such exists) whose sine and cosine will adjust the zero crossings of the longitudinal and lateral correlations to a common value of .25 wave lengths. The nearest approach to this is provided by an angle of 35° (which, incidentally, coincides with the axis of maximum intensity). Figure IV B-4 illustrates the results and gives a comparison with the correlation property of a simple wave

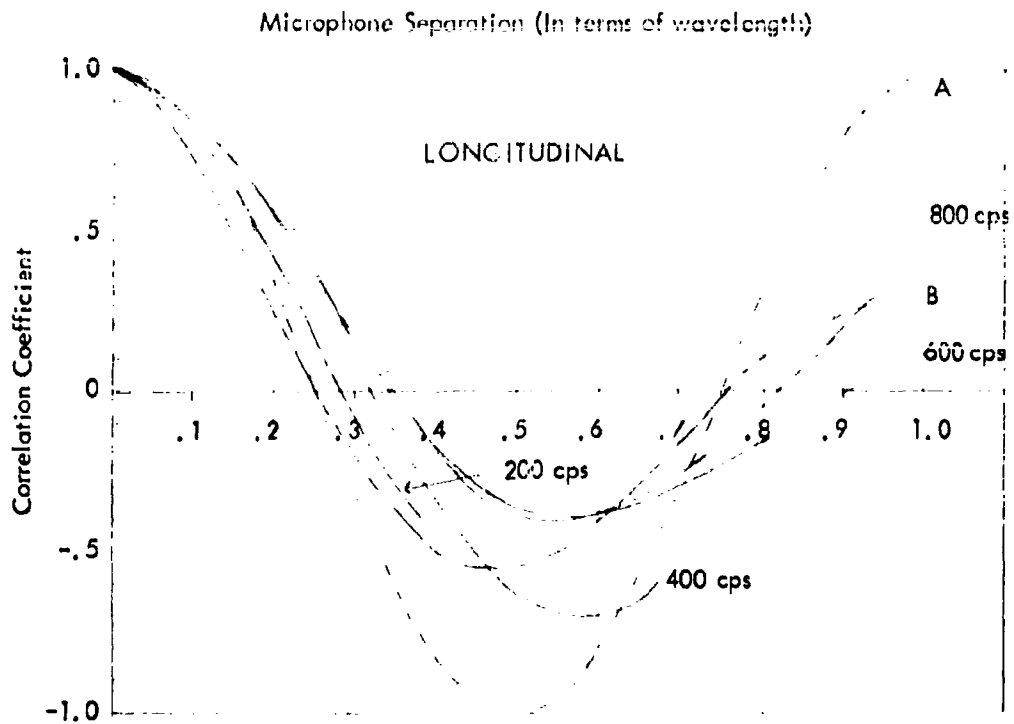
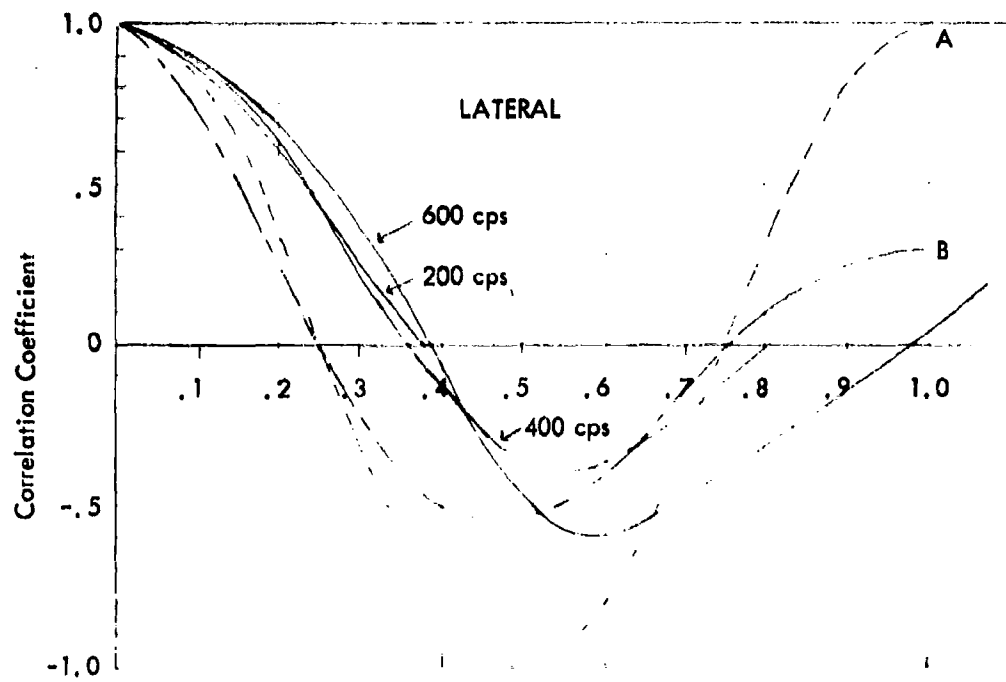
*

"Random Vibrations" edited by S. Crandall, Wiley and Sons, Inc., 1958, See Chapter 8 by Alan Powell



JET ENGINE CORRELATIONS

FIGURE IV B-3



COMPARISONS OF CORRELATIONS

FIGURE IV B-4

(curve A). The observed location of the zero crossings indicate that a fair approximation to the correlation function of the jet field can be obtained from the correlation of a simple plane wave propagating along the direction of maximum intensity. To carry this a step further, consider the correlation of a train of plane waves propagating along this axis. If the waves have a continuous distribution of frequencies in a narrow band $2b$ centered at the frequency ω then the correlation along the axis is given by $\frac{1}{b} \tau \sin b\tau \cos \omega\tau$. However, if the 'waves' considered are the output of a simple filter (having the response function of a simple tuned circuit) the measured correlation would be $e^{-b\tau} \cos \omega\tau$ where b is the half-bandwidth of the filter. Now the results illustrated were obtained by filtering the jet field by filters whose bandwidths lay in the range 38% to 41%. Using an average value of 40% gives the curve labelled B in Figure IV B-4 and it can be seen that this gives a plausible explanation of the observed or apparent attenuation of the correlation as the microphone separation increases.

Since panels and other structure produce Q's of the order of 20 or 30, the effective bandwidth of such structural filters is of the order of 3% to 5%; consequently, the correlation properties to be used in calculations of panel response may be expected to be substantially different from those reported by Howes, et al.

It is recommended that correlation measurements made in jet fields be based on bandwidths that are representative of the Q's encountered with practical structures. In general, the test facilities visited do not make correlation measurements and make no provision for including such data (if it were available) in their fatigue prediction techniques. The assumption is made that most panels are small when compared with the sound wave lengths of interest (2 to 10 ft.) so that the noise is taken as correlated over a panel and a uniform pressure field is assumed to exist. An examination of Figure IV B-4 shows that this is not a very good assumption when dealing with panels larger than one foot in width and frequencies higher than 300 cps. Certainly in future work, efforts should be made to account for the effects of spatial correlation. If the proper measurements were available, we believe that the effects might be approximated

by orienting a specimen at a specific angle to a progressive wave field. The possibility of doing this and the problems that arise are discussed in Section IV D-3.

Lockheed Aircraft has performed a project for WADD that involved making correlation measurements and using these in calculating the response of a 6" x 20" panel. We received the report* too late to permit a thorough review; however, the principle results confirm the distribution of sound pressure levels and correlation coefficients reported by Howes, et al.

IV C - EXCITATION REQUIREMENTS AND SOUND SOURCES

IV C-1. General Discussion of Requirements

An examination of Table III Q would indicate that many types of noise sources are used in sonic fatigue work. While this is true, probably 75% or more of the work is performed with discrete frequency sirens or jet engines, and the other sources have somewhat limited use in research and development and for making comparison or proof tests of structures. For example, twelve of the fifteen facilities visited had some type of discrete frequency siren that was used for testing and most of them also had jet engine stands available.

The noise sources break down into discrete frequency types and broad band types. The discrete frequency units are used for design testing* while the broad band sources are used for proof testing; broad band sources have been used for design (Boeing, Seattle on the KC-135 aircraft for example) but this is not a common procedure.

A consideration of the way a discrete frequency source is used indicates that

*"A Study of the Characteristics of Modern Engine Noise and the Response Characteristics of Structures", Lockheed Report No. 13,700; Contract No. AF33(616)-5546.

**The words "design testing" are used in the sense discussed in Section IV A. Many companies use an accelerated siren test on panels and refer to this as a proof test. According to the usage in this report such a test would be classified as a design test.

It should meet the following minimum requirements.

- (1) It should maintain the sound pressure level constant within fairly narrow limits over the duration of the test. This is to assure a knowledge of the actual test level since small errors in the test pressure can cause large errors in the fatigue life.
- (2) It should maintain constant frequency and should not drift.
- (3) It should produce most of its energy at the fundamental frequency. This is to avoid the possibility of unknown resonant panel response at other modes.
- (4) Its efficiency should be no less than 8 to 10%; otherwise the operation becomes unnecessarily expensive.
- (5) It should produce at least between 20,000 and 30,000 acoustic watts over the important structural frequency range 100 to 1000 cps. This is necessary to generate destructive sound pressure levels over average panel areas.

Broad band sources, since they are most frequently used as proof testing devices, should simulate the operational sonic environment of the structure as closely as possible. The properties that must be considered are the spectrum shape and level, the statistical distribution of the peak pressures, and the spatial correlation and intensity distribution over the structure. In aircraft work jet engines are usually the source of service noise (the best available information is that for speeds less than Mach 3 or 4, boundary layer noise is not a significant cause of sonic fatigue), and the behavior of a noise source can be compared with that of a jet engine to decide if the source has satisfactory properties.

The requirements for noise sources for use in R and D work, as had been stated, depend upon the kind of work. But there is a great need for precise control of whatever noise source is used. For example, if a discrete frequency siren is to be used in making response measurements on a complex panel, the harmonic content should be low (the wave shape should be approximately sinusoidal) and the frequency and noise level should be constant.

IV C-2. Noise Sources

(a) Jet Engines

Jet engines can have sound power outputs that range as high as 175 to 180 db with sound pressure levels as high as 170 to 175 db over the frequency range 100 to 500 cps. The noise spectrum can be quite flat over this range. The noise output of a jet is random and broad band, and the values referred to as being "flat" are the root mean square pressures in a one cycle bandwidth over a finite time period. The noise output of a jet depends on the thrust of the engine, the air temperature and pressure, the type of engine, and it can change during the operation of the engine. For example, the sound pressure measured at a particular location may increase during the first five minutes of operation and then decrease to some fairly constant value. The control settings on a jet engine will tend to drift during operation and this will cause a variation in sound pressure level. Thus, jet engine tests usually are run for fairly long periods of time (several hours) to average out whatever fluctuations in sound pressure level may occur. The jet engine has an efficiency as a noise producer that is of the order of 1/2% to 1% and is therefore an expensive source of noise energy. The jet engines used for testing by the various facilities cost approximately \$500.00 an hour to operate. This figure does not include overhead and, since the life of a jet engine running at full power with afterburners is limited, the overhead could be quite high.

Since jets are the cause of most sonic fatigue on aircraft structures, they are an obvious choice as a noise source for use in proof testing, and practically all such testing is done with jet engines (the full life tests performed at Martin, Denver on the Titan Missile structure by means of a random siren are an exception to this). Douglas uses a jet engine on a test stand to proof test the panels that have been developed with the use of a discrete siren. Convair, Fort Worth uses a semi-enclosed cell with an engine mounted on a section of the B-58 wing, and also the actual full scale B-58 aircraft. Boeing, Wichita uses an elaborate half wing (4 engines) facility for proof tests. Martin, Baltimore and Boeing, Seattle have used various jet engine set-ups that include full

scale sections, and panels of aircraft. The most reliable proof test is that which is carried out in a full scale airplane. Such test set-ups, however, are also the most costly. The sonic wing facility at Boeing, Wichita for example, costs an estimated \$30,000 an hour (including amortization) to run.

When stationary jet engines are used for testing, they are not necessarily the same engines that are used on the aircraft, and care must be taken to locate the specimen in the sound field so that the service level and spectrum (between say 100 to 1000 cps) is approximated. If this requires that the specimen be in a very different position (with respect to the engine) to that which it occupies in service, then the correlation properties that would exist in operation might not be reproduced.

In general, jet engines mounted on open test stands simulate the operating environment quite well. This may not be true of engines mounted in semi-enclosed cells, and is certainly not true of engines mounted in closed cells since the reflections from the walls distort the noise spectrum and completely change the correlation properties of the field. In closed-cell testing the specimen can be positioned to obtain the proper rms strain level but, since the noise spectrum has been distorted, the strain spectrum for multi-mode response may be modified and with it the fatigue life. Closed cell testing should be avoided if possible.

Jet engines can be used for designing structure, but because of the expense involved, are not to be preferred for this use.

(b) Modulated Air Flow Speakers

The modulated air flow speaker has been used quite extensively for testing of electronic components and small packages and to some extent for structural fatigue testing. Boeing, Seattle (see Section III-A) has a facility that uses four speakers (developed and marketed by Ling Electronics) in parallel to produce a random noise environment for both normal and progressive wave testing. The advantage of such a system is that almost any desired spectrum shape is possible in the frequency range 100 to 2000 cps. The overall sound pressure level produced in Boeing's progressive wave set-up

is approximately 164 db (8000 acoustic watts). Since a minimum of 8 speakers would be required to raise the level 3 db, a serious limitation exists on the use of such a system to reach levels of say 174 db (approximately 40 speakers). These speakers cost \$2500 each so that 40 speakers by themselves would cost about \$100,000. There would also be a physical difficulty in utilizing 40 speakers. The 164 db set-up at Boeing utilized a rectangular test section that is only 5" deep, and the output of the 4 speakers is channeled into this narrow section. If a large number of speakers were to be used, the section thickness would have to be increased, thus increasing the volume of the chamber and decreasing the noise level. Using large numbers of such speakers does not appear feasible for design testing primarily because it is considerably cheaper to use sirens. As proof testing sources on panels or small structures, however, with the performance specifications quoted by Ling Electronics, modulated air speaker arrays would be feasible. The jet engine spectrum could be duplicated up to about 2000 cps and, with a reported efficiency of around 8%, these sources would be considerably less expensive to operate than the jet engines. The Ling Electronics speaker certainly should be investigated further as a noise source for use in testing.

(c) Electrodynamic Speakers

Electrodynamic speakers are not generally used for sonic fatigue testing since they have difficulty producing sound pressure levels above 150 db in any usable working space. Test chambers using electrodynamic speakers are used for testing electronic components since an increased noise level can be obtained by using a reverberant chamber and this reverberant field is often representative of the operating environment of the component.

The main use of electrodynamic speakers in sonic fatigue work is as a source to excite a test panel at a low SPL (130 to 140 db) in order to establish patterns of vibration and determine points of maximum stress. This information is then used to locate strain gages on the specimen for testing in a siren or jet engine facility. This use of speakers is a matter of testing convenience, and most facilities determine modal patterns

by exposing their specimen to a low level siren excitation.

(d) Air Jets

NASA, Langley has developed a powerful air jet facility and, with recent modifications have obtained levels as high as 170 db that very closely simulate the noise spectrum of jet and rocket engines (it also probably simulates the correlation properties, although they have not been measured). Such a facility is possible at NASA because of the availability of a large tank farm (135,000 cubic ft. of air at 600 psi). The operating cost of this facility at maximum output would be approximately \$400/hr. without overhead. It is obvious that unless such a tank farm is required for use by some other testing facility (such as a blow down wind tunnel) and is available at off times for acoustic testing, the initial investment is prohibitively high for sonic fatigue testing. The operating cost of this size air jet is comparable to that of a jet engine so that for proof testing of structures there is little point in considering it. As it exists at NASA, Langley, the air jet has some use as a tool for doing sonic fatigue research. By varying the pipe configuration the noise spectrum can be roughly shaped and the control of level and spectrum is more precise than in a jet engine facility. The possibility of using the tremendous quantities of air available at Langley with random sirens or modulated speakers (with efficiencies of 8% to 10%) should be considered.

Most other air jets that exist are of very low noise level and are used by universities for research or by companies (North American, Columbus and McDonnell, St. Louis) for testing of electronic components.

(e) Discrete Frequency Sirens

The primary noise source used to design and develop structures to withstand sonic fatigue is the discrete frequency siren. Twelve of the 15 facilities have sirens for this purpose. Popularity of the discrete frequency siren as a design tool is due to its simplicity, economy of operation, and its ability to provide high acoustic outputs at the frequency to which the test structure is most sensitive. Sirens can operate at 155 to 175 db

over the frequency range 50 to 10,000 cps, but most of them are designed to operate over the frequency range 100 to 1000 cps. Some facilities use sirens of their own design (Boeing; Martin, Baltimore; McDonnell; Convair, Fort Worth) while others use the designs of Leonard and Rudnick and of Bolt Beranek and Newman, Inc.

(1) Leonard and Rudnick Design

The best available data from facilities using a siren of the Leonard and Rudnick design is given in the descriptions of the Douglas and North American, Columbus facilities (Sections III F and III L). These facilities are both of the progressive wave type. The sound pressure level developed in the progressive wave test section is approximately 170 db. Harmonic content measurements over some of the frequency range show that the harmonics are down 8 to 15 db from the fundamental. Being 15 db down from the fundamental is sufficient to insure that the excitation energy is concentrated at the frequency of interest and that no other modes are excited in any significant way. At those frequencies where the harmonic content is 8 db down, there is a possibility that other modes may be excited (although weakly), and the panel strain gage output should be checked for this condition. It should be recognized that the possibility of exciting higher modes by these harmonics is quite small, and that the Leonard and Rudnick siren is adequate for discrete frequency testing.

The SPL control system varies from facility to facility. Whether the variation in SPL is less than ± 1 db (which should be the maximum variation) at these facilities is not known and is a condition that should be checked. There is nothing in the design of the siren that would prevent it from being controlled within that tolerance.

(2) Bolt Beranek and Newman Design

In addition to the facility at BBN, the Bolt Beranek and Newman siren design will be used in the large WADD facility and has been installed in the North American, Los Angeles facility. A great deal of emphasis was placed on the siren's ability to produce a pure tone sine wave. A complete noise source includes two sirens,

one of which operates over the frequency range 50 to 1000 cps and the other over the range 500 to 10,000 cps. Most of the data available on the performance characteristics come from the facility available at BBN which is discussed in Section III C. The BBN system is designed primarily for progressive wave testing (although normal incidence testing may also be performed) and the best example of this facility for use as a tool for design and development is given in the description of the North American, Los Angeles facility (Section III M). The design specifications are given in this description but actual data on its performance were not available since the facility was just being completed. The maximum power that is to be developed is 27,870 acoustic watts which will give sound pressure levels of 170 db over an area of 3 square feet.

Measurements made over some of the frequency range of the BBN 12" siren showed the harmonic content to be 15 to 20 db down from the fundamental and that the SPL can be controlled within ± 1 db. The siren appears to be adequate for discrete frequency testing, although more measurements should be made to substantiate this.

The estimated cost of the Los Angeles facility is approximately \$338,000.

This cost includes a large reverberation chamber with provision for combined vibration and sonic testing of components and other accessories not necessary for the investigation of the sonic fatigue of structure. BBN estimates that a facility that closely resembles their own can be designed and built for approximately \$125,000 to \$150,000.

(3) In-House Designs

The facility descriptions give some data on the sirens (perforated disc type) that are used at Martin, Boeing, and McDonnell and Convair, Fort Worth. The data given by Convair, Fort Worth on harmonic content is more an indication of chamber characteristics than the siren output. The Martin siren shows high harmonic content at certain frequencies (see Figure III H-4) and care must be used in testing. It should be pointed out that the data given by Martin in this figure is perhaps the most complete given on harmonic content of any existing siren facility, and that, in general, data on siren characteristics is surprisingly meager. There is not enough information on the

performance of the "in-house" sirens to say whether the SPL can be controlled within ± 1 db or whether the harmonic content is high enough so that it causes concern in discrete frequency testing. It is probable that these sources are adequate for such testing but more data is needed to show this.

It should be noted that even with a very high harmonic content a siren can be a good design tool; the method of design and the method of testing, however, must be such as to take into account the other modes that might be generated (the existing methods do not do this) and this would not be a simple matter.

(f) Arrays of Discrete Frequency Sirens

The facility at WADD is designed to simulate broad band random noise by means of groups of discrete frequency sirens. The BBN sirens for use in the facility are designed for this. Two ways of operating each of the sirens have been considered. The amplitude can be modulated as described in Section III P or the frequency of the siren can be varied over a narrow range (± 25 cps around the center frequency). The problem is to obtain the best approximation to broad band random noise when the sirens are used in groups. These approaches were analyzed and some tests were performed on electrical analogies of the siren array and the results given in the report "Summary Analysis Report on the Wide Band Sound Source for the WADD Facility", September 1, 1960*.

The procedure of modulating the frequency of each siren apparently gives a better approximation of the random noise than modulating the amplitude. This is when the sweep frequency rates of the sirens are incommensurate with one another. For example, in application to a single resonant system as the number of pure tone sirens with incommensurate sweep frequencies is increased, a Rayleigh distribution is approached. The

*BBN Report No. 685 to the WADD Flight Dynamics Laboratory Contract No. AF33(616)-5274
Project No. 1370 - Task No. 13963

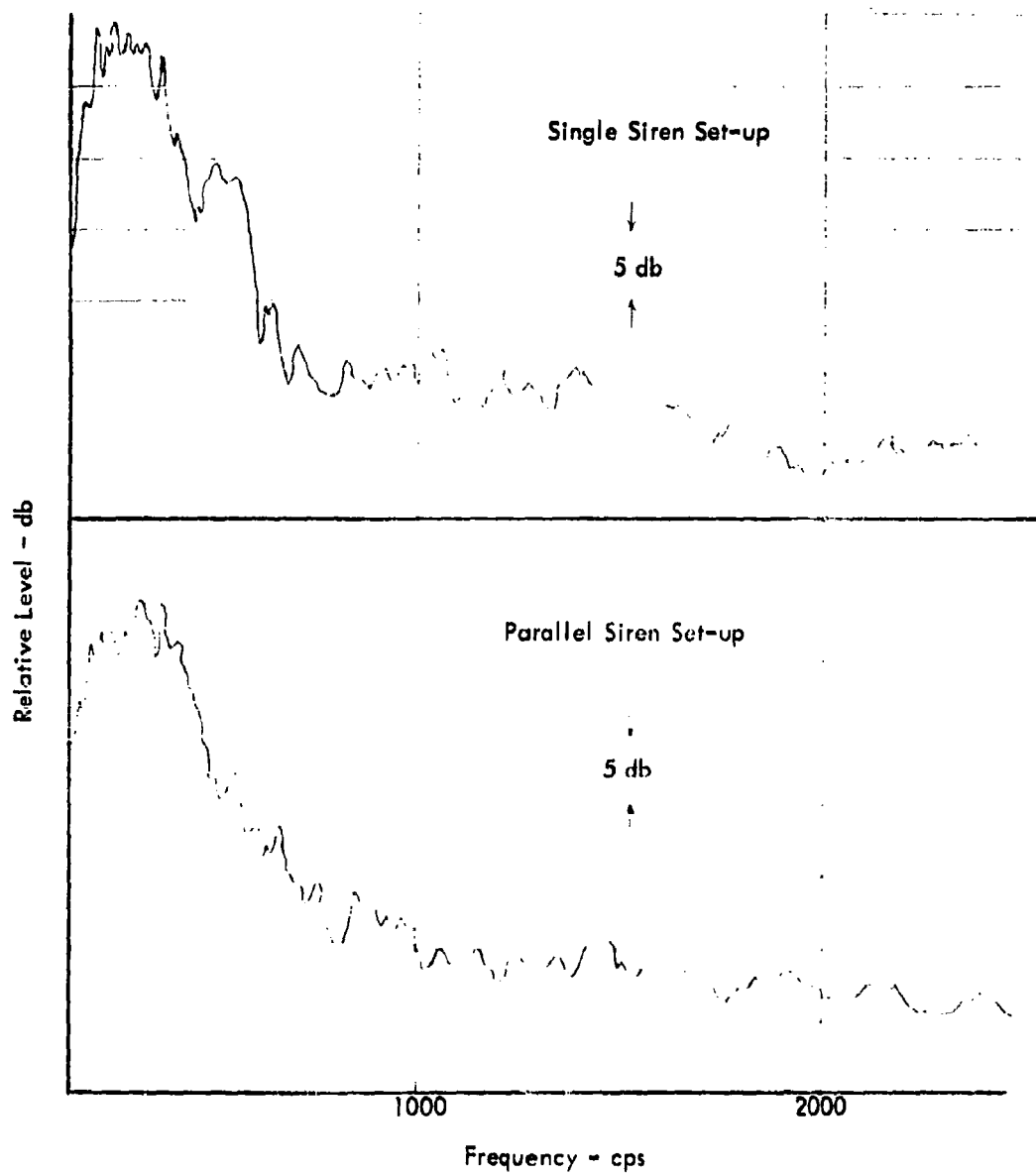
analysis also indicated that the spectrum obtained for groups of sirens (with frequency modulation) has an amplitude distribution similar to that of a jet engine when the simulated spectrum is sampled over a sufficiently long period of time.

Since the arrays of sirens have not yet been assembled (or the necessary sirens built) and no test data exists, it is not possible to say how closely the broad band noise will be simulated. One of the things that must be observed in the tests is the effect of time scale on the response of the test structure. Noise that is synthesized in this manner will tend to have its peaks occur much more successively than they would in a random field and, thus, the structure may be able to respond to a given frequency more readily than it could if the noise were random.

The siren array noise source has wide flexibility because the energy can be spread over a broad band or concentrated within a narrow band to obtain extremely high sound pressure levels. This may be necessary for special proof tests of future missiles where overall noise levels above 180 db must be considered.

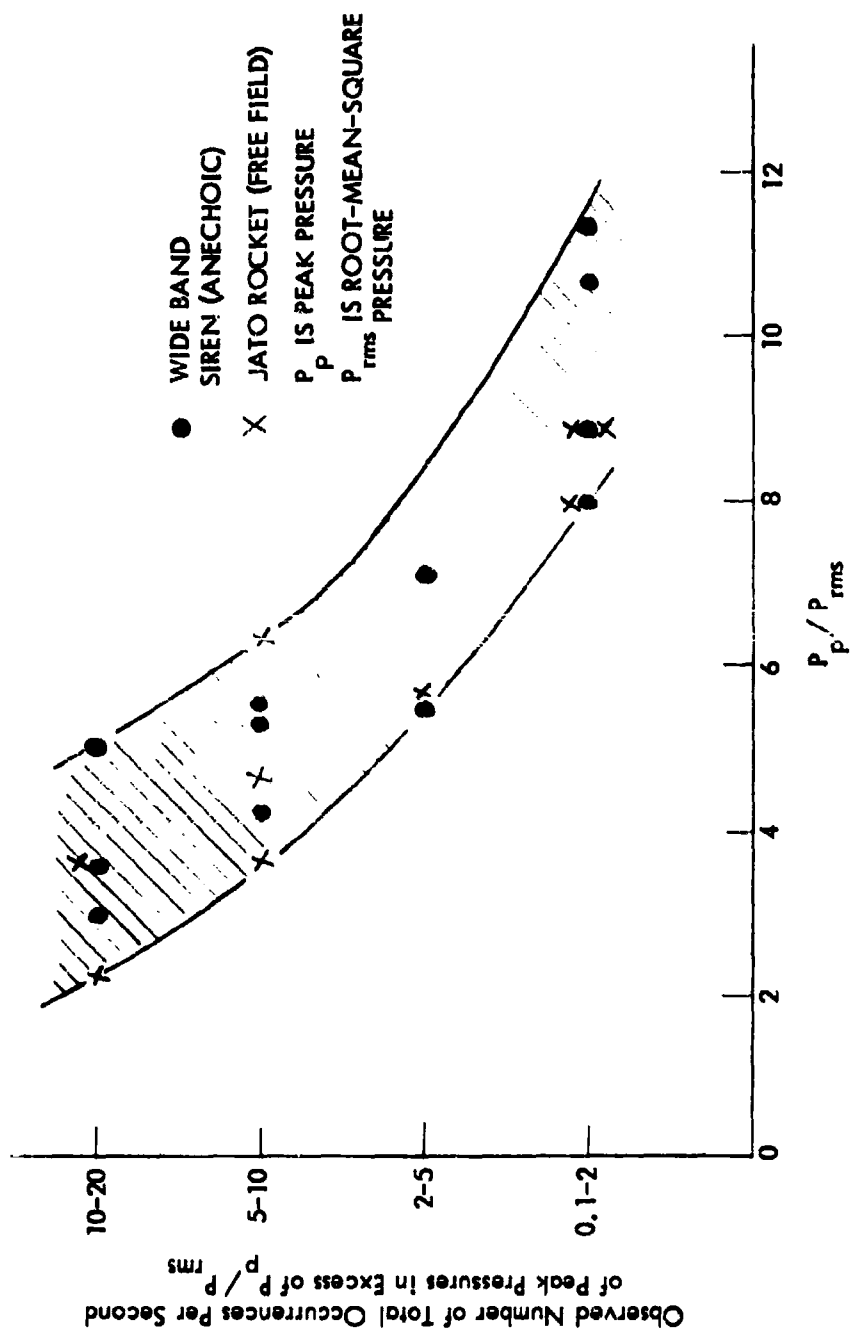
(g) The Broad Band Siren

Several models of a wide band siren developed at WADD have been built and investigated. The first of these was developed at the Aeromedical Laboratory and later similar designs were built at Martin, Denver and North American Aviation, Columbus. Basically, this type of siren has a single nozzle and four overlapping rotors with randomly spaced teeth passing in front of the nozzle. Martin, Denver (Section III-1) has used sirens of this type for testing large missile segments. Figure IV C-1 shows a narrow band (5 cps) plot of the relative level produced by a single siren and two sirens in parallel when using the same air supply. Figure IV C-2 is a peak distribution plot of the WADD siren as compared with that of a Jato Rocket. Figures IV C-3 and IV C-4 are narrow band analyses of the free field sound pressures generated by a turbojet engine with afterburner and of the sound pressure on the surface of a flat plate. From a comparison of these plots, it can be said that the wide band siren gives good simulation of jet and rocket engine spectra and peak pressure distribution. There is approximately a 30 db



NARROW BAND - 5 cps
ANALYSIS OF RANDOM SIREN

FIGURE IV C-1



PEAK PRESSURE DISTRIBUTIONS

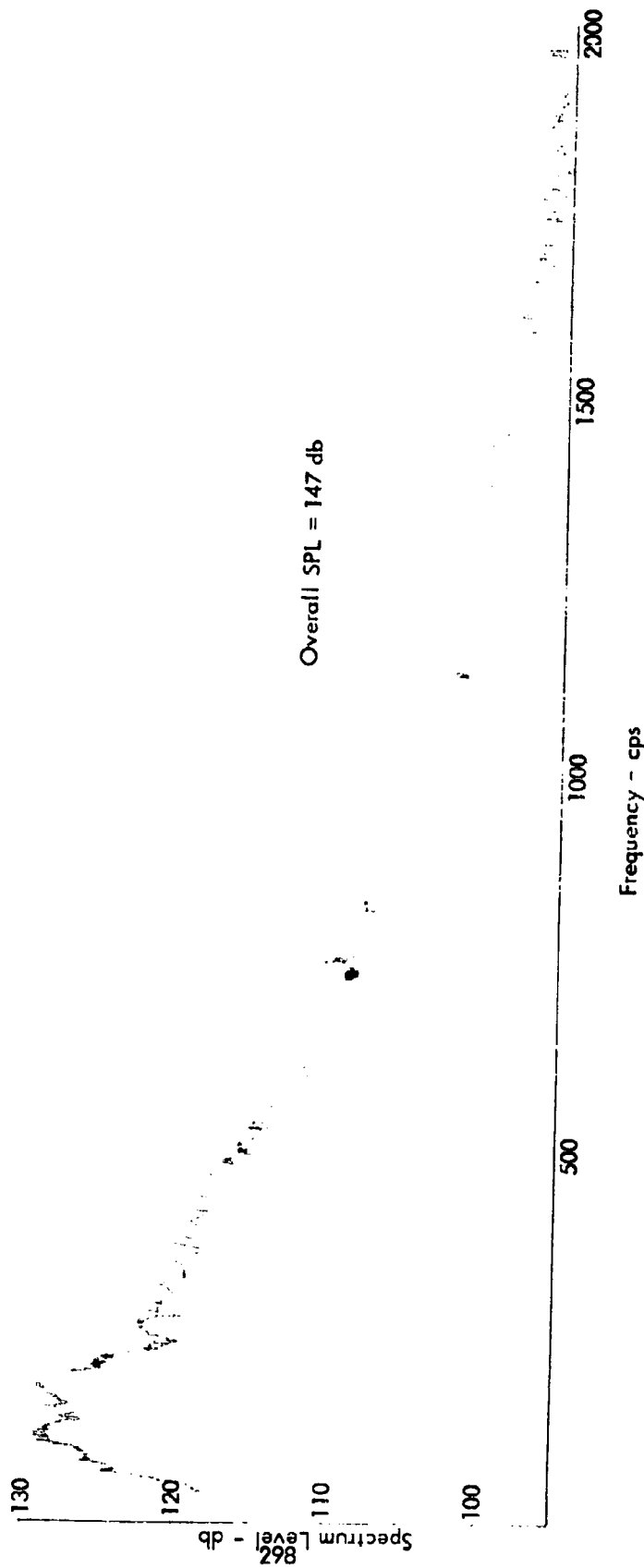
FIGURE IV C-2

YJ-79 Turbojet Engine
(With Afterburner)

Taken from LR-13700
(WADD TR-60-220)

Free Field Survey

Axial distance downstream from nozzle exit 35 ft. - 15.5 nozzle diameters
Radial distance from jet axis - 15 ft. - 6.7 nozzle diameters



NARROW BAND ANALYSIS (10 cps) OF JET ENGINE NOISE

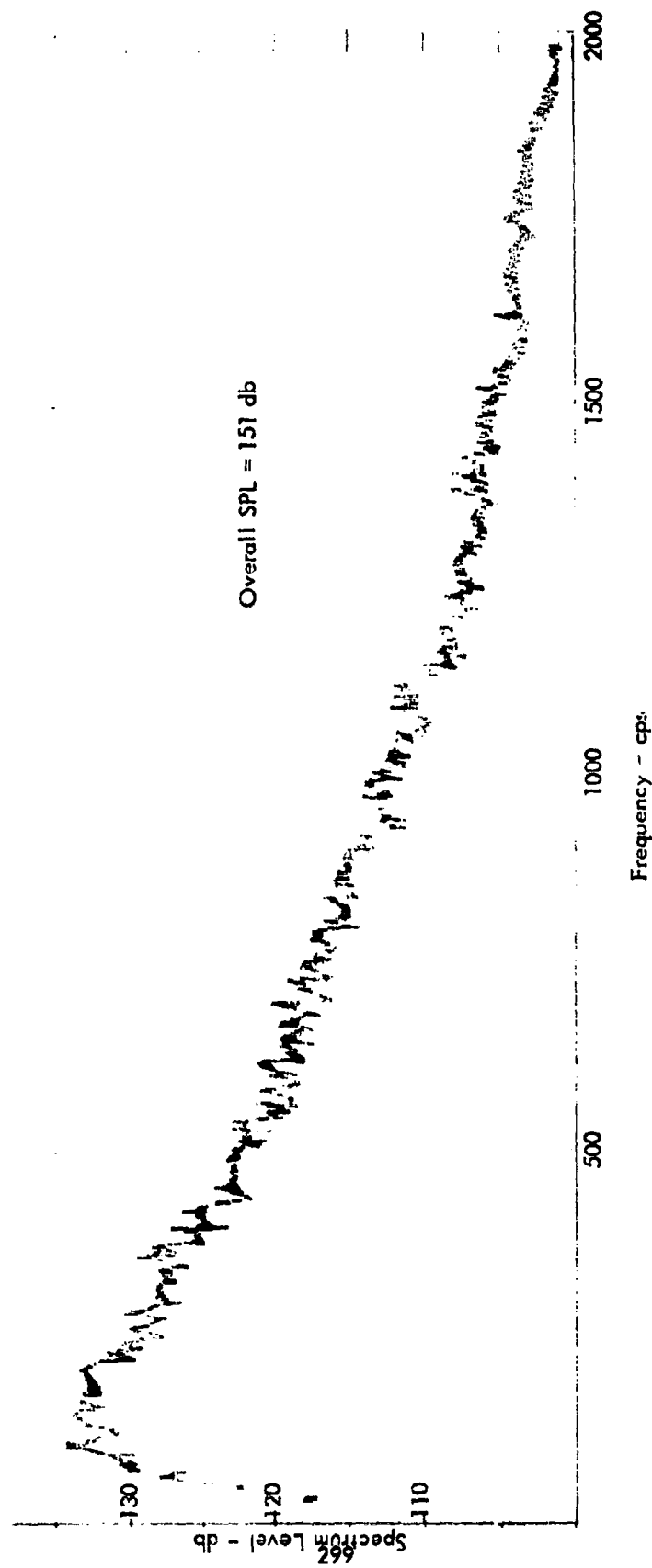
FIGURE IV C-3

YJ-79 Turbojet Engine
(With Afterburner)

Taken from LR-13700
(WADD TR-60-220)

Microphone Position Against Flat Panel

Axial distance downstream from nozzle exit 40.1 ft. - 17.8 nozzle diameters
Radial distance from jet axis - 15 ft. - 6.6 nozzle diameters



NARROW BAND ANALYSIS (10 cps) OF JET ENGINE NOISE

FIGURE IV C-4

drop in the spectra for both the siren and the jet noise over a 2000 cps range (based on a narrow band analysis plot) and most of the energy is in both cases concentrated over the first 500 cycles. The largest obtained efficiency of the siren developed at WADD is in the vicinity of 8 to 10%, and the efficiency of the sirens developed at Martin is approximately 7%. As presently designed, the sirens are capable of developing 20,000 to 30,000 acoustic watts which is of the order of the BBN siren. It is possible, therefore, in a facility of the type designed at WADD that broad band sirens in groups of 25 to 35 sirens could develop as much as one million acoustic watts (the input air pressure at WADD would have to be increased to obtain the necessary siren efficiency). The disadvantages of such a source is that the spectrum shape and bandwidths can only be slightly altered by varying relative speeds of the 4 rotors and that it is not possible to pack all of the energy into a narrow band. Also, the jet engine spectra shown in Figures IVC-3 and IVC-4 are for particular locations. Other jet engines or measurements made at other locations show flat noise spectra over a wider frequency range or spectra with discrete tones. At the present time, correlation properties of jet engine noise sources are still under investigation. When more is known about these properties and their effects on structure, investigations should be made to see if the correlation properties of the jet can or must be reproduced by the siren (this is also true when using arrays of sirens for proof testing).

When comparing the use of a wide band siren to that of a jet engine as a proof testing device, the wide band siren shows significant economic advantage. The operating cost of a jet engine, for example, would be in the vicinity of \$500 per hour whereas the operating cost of a wide band siren would be between \$50 and \$100 an hour. The total cost for either a wide band siren facility or a jet engine facility would be approximately the same (\$250,000). Hence serious consideration should be given to developing a wide band siren as a proof test device.

(h) Noise Generator

A broad band noise source that has been under development is the poppet

type air valve used by Northrop. This generator (see Section III-N) is essentially an airstream modulator. The poppet valve is given a lift of random amplitude and frequency by a vibration exciter and the pressure of the air supply is such that highly non-linear effects due to strong shock waves are produced in the throat of the horn. The acoustical output resulting from this device is claimed to have a power level of 175 db (31,600 acoustic watts). Unfortunately no details of the characteristics of the random output are available and little can be said about it.

(i) Combustion Noise Sources

A preliminary analysis was made in the aforementioned report (BBN Report 685) of the possibility of using an internal combustion device as a broad band sound source. This is the idea of generating noise by introducing heat into an air stream (exploding fuel in an internal combustion engine, for example, and trying to maximize the noise from the exhaust port). All that could be concluded is that such noise sources looked reasonably feasible on paper and that some experimental work should be performed. Anyone building a sonic facility within the next five years should investigate developments in combustion sources as they may prove useful.

IV C-3. Sources for Design Testing

Discrete frequency sirens are commonly used for design testing. They are cheap and the present methods of analysis are sufficiently good so that a panel design can be established for proof testing without an excessive number of design tests. In general, the more complex the response of the panel, the less accurate are the results of a siren test. To handle panels which have a definite multi-mode response, two or three discrete frequency sirens could be used to excite the modes simultaneously and thus permit a more accurate analysis (North American, Los Angeles is going to investigate the use of two sirens for this purpose). Thus it appears that so long as design tests are necessary, discrete frequency sirens can do the job. As research is performed and theories of analysis are improved the necessity of destructive design tests may decrease although it

appears that within the foreseeable future, tests to establish the dynamical and physical characteristics of a structure (stress concentration factors, damping factors, non-linear response characteristics, natural frequencies and modal responses) will be required.

Broad band sources can be used in design but they would be much more costly than discrete frequency sources. If an accelerated discrete frequency siren test is performed in 20 minutes, the broad band source (say over the range 100 to 500 cps) that would do the job in 20 minutes would have to put out several times the power of the siren. If the test is carried on for a longer time, the power requirement would be lessened but obviously the testing cost is higher than the 20 minute siren test.

Broad band sources would have the advantage that they would excite multi-mode response in the structure but correction factors for non-linearity would still have to be used when making accelerated tests. Also specimen boundary condition uncertainty would still exist.

A jet engine is not recommended for design work unless the engine has to be operated for other reasons and the expense is not allocated to design. Broad band sources such as the Aeromedical Laboratory siren and the air modulated speaker are much more efficient noise producers than a jet engine and if they are available and can produce the necessary SPL, they are a good design tool. Clearly they are more expensive to operate than discrete frequency sirens but this is not an order of magnitude difference and if such sources are available, the percentage increase in the cost of a test (considering specimen cost, operating labor, power cost, engineering labor, and set-up time) would be small. If a new design facility were to be built and levels of the order of 175 db were required, then discrete frequency sources would be much cheaper than the broad band and are to be recommended.

IV C-4 Sources for Proof Testing

The most commonly used source for proof testing is the jet engine. In fact, within our use of the expression "proof testing", jet engines are the only sources used for testing aircraft structures. Since these sources can so closely duplicate service

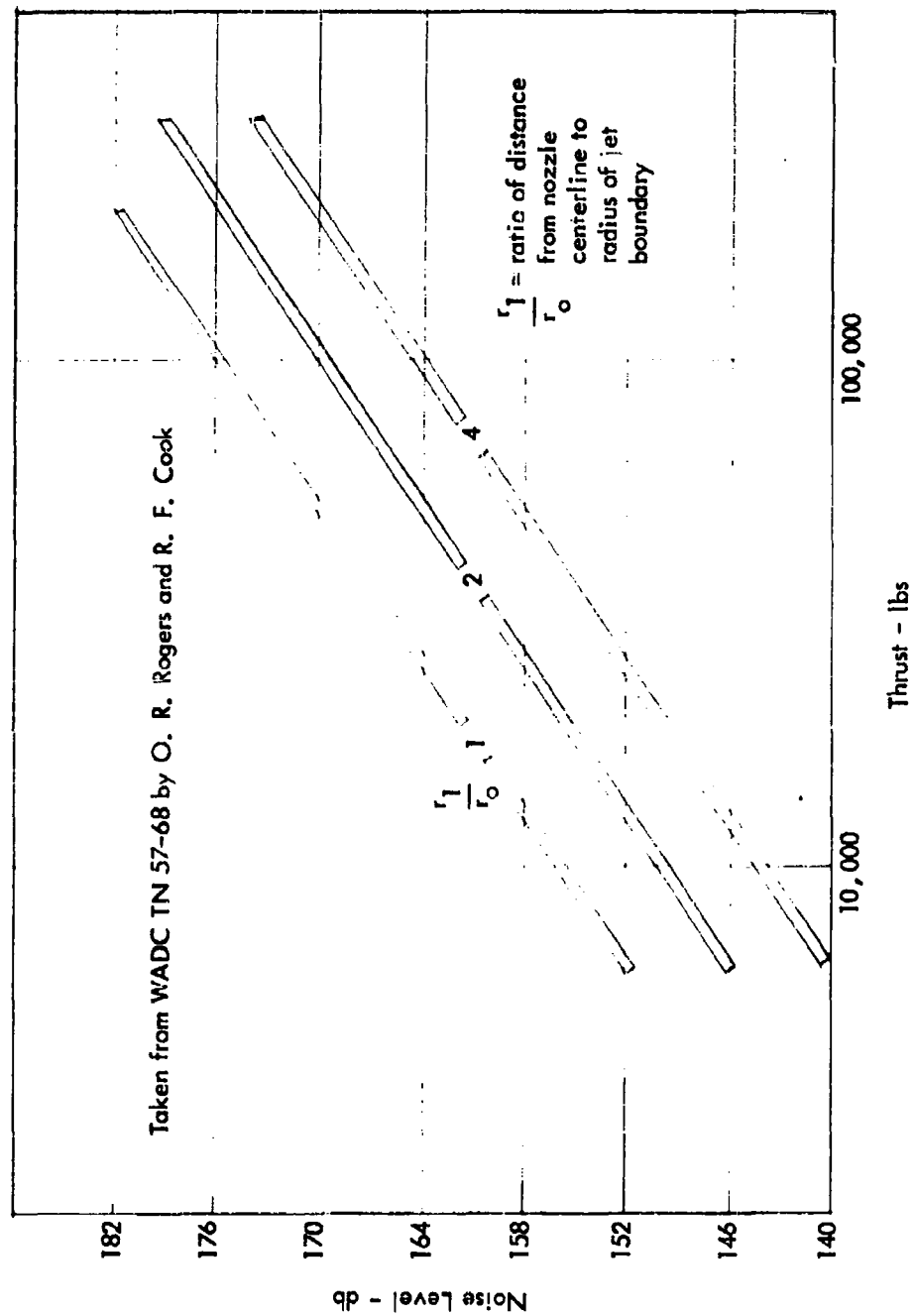
conditions, it is not possible to suggest an alternative source on technical grounds (although, as has been discussed, there are desirable and undesirable ways of using the jets), the suggestion can only be made on economic grounds, and it is primarily for economic motives that other sources are considered in aircraft work.

The situation is somewhat different when the proof testing of rocket vehicle structure is considered. Rockets produce broad band random noise that has a spectrum quite similar to jet noise. Because of the enormous thrusts of rocket engines (engines up to 1.5 million pounds of thrust are under design) they can produce higher noise levels than jet engines. Figures IV C-5 and IV C-6 show the trend of noise levels for rockets and jets and the predicted approximate levels for some large rockets. The type of rocket noise environment that is of interest will depend upon the particular rocket. The Minuteman and the Titan missiles, for example, would experience a reverberant field during an "in-silo" launch and the possibility of coupling between the chamber and the missile must be considered. In general, rocket structures should be proof tested with broad band random noise and, as with aircraft, frequencies below 500 cps will be the most damaging. When rockets with noise levels above 180 db are considered, only discrete frequency tests or "tie down" tests on the missile (an expensive and unlikely procedure) can be performed since broad band tests at this level are not possible with any of the facilities to be available within the next two to four years.

In any case, the broad band siren has been used for proof testing the Titan missile and the modulated air stream speaker has been used for testing the Minuteman.

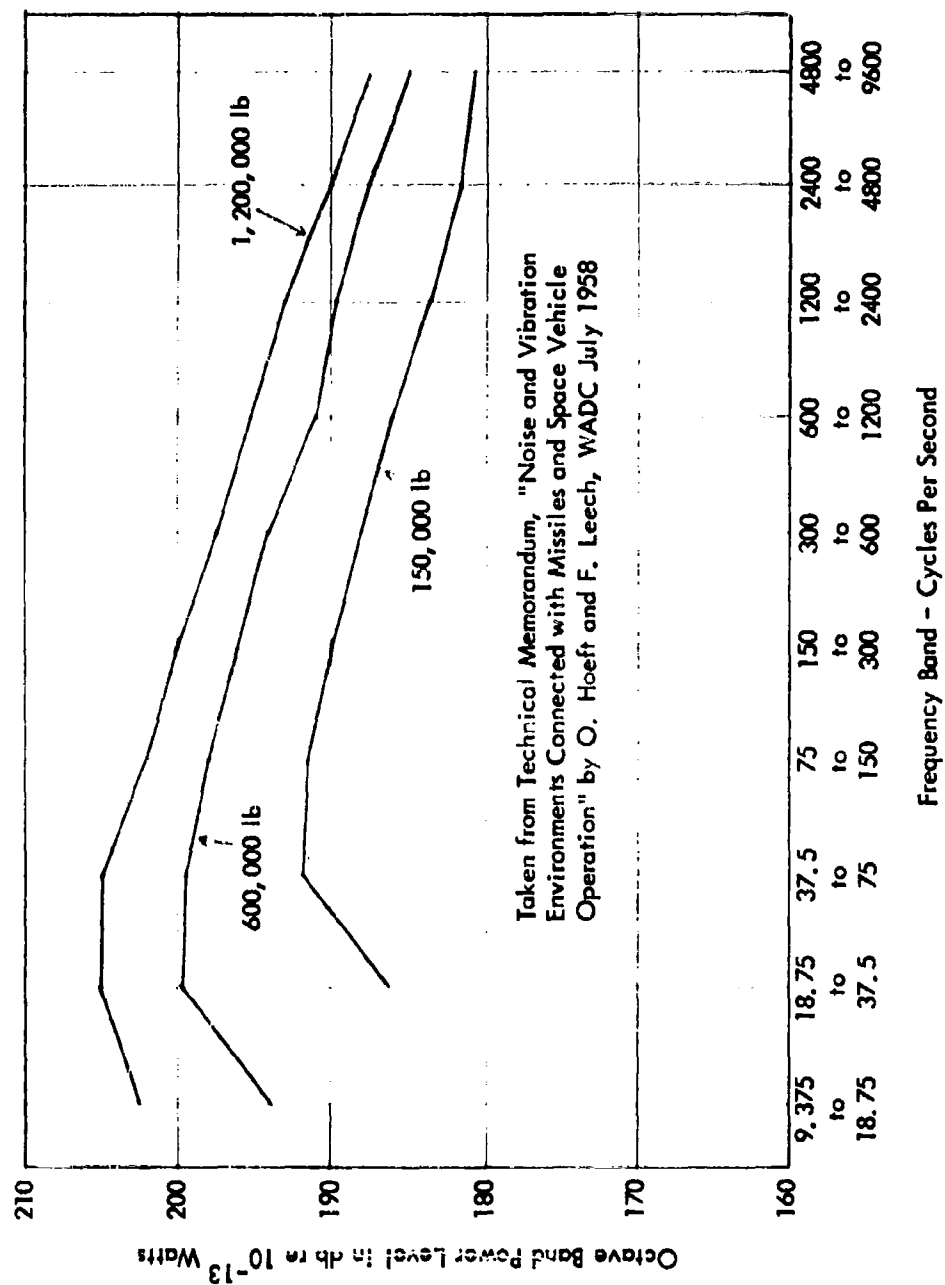
The broad band siren can reproduce some jet spectra quite closely over the range 100 to 500 cps and, although work must be done to evaluate the correlation properties of the siren noise, it appears that such a device could be used for proof testing both aircraft and missile structure at between one-tenth and one-fifth the operating cost of the jet engine.

The modulated air stream speaker can duplicate a jet engine and rocket spectrum up to about 2000 cps and, with an efficiency of around 8% they are considerably less expensive to operate than jet engines. Small arrays (4 speakers) have been used in



TREND OF EXTERNAL OVERALL NOISE LEVELS FOR JET AND ROCKET NOISE

FIGURE IV C-5



PREDICTED ACOUSTIC POWER LEVEL SPECTRUM FOR 3 LARGE ROCKETS

FIGURE IV C-6

proof testing and larger arrays should be considered as replacements for the jet engine.

The other source that can be considered is the array of discrete frequency sirens (not enough is known of the characteristics of the Norair generator to allow an evaluation to be made). This is the type of source that is to be used in the large WADD facility. Analysis indicates that the necessary broad band spectrum will be simulated but only the actual operation of the sirens will show how closely. There is a question of simulating the correlation properties of jet noise with this source and this will also have to be investigated.

IV C-5 Sources for Research and Development

Since quite obviously any of the noise sources can be used for R and D work, the question should be asked which of the noise sources would have the most advantages in terms of application and cost? If a source is to have wide application, it should have the following capabilities:

1. Be able to develop a high intensity discrete frequency tone that is sinusoidal in character. It is desirable to be able to define the sound field in relatively simple mathematical terms so that the mathematical analysis of the structural response does not become impossibly complicated.
2. It should maintain a constant level (± 1 db), the frequency should be controllable within $\pm 1/2\%$ of the desired frequency (preferably closer) and it should cover at least the range 100 to 1000 cps with a sound pressure level of approximately 170 db.
3. It should be able to produce broad band random noise to simulate jet and rocket noise. This is necessary in the investigation of multi-mode response of structures and in the comparison of discrete frequency and random response.
4. The shape of the broad band spectrum should be controllable so that various types of spectra can be examined, and the peak pressures should be around 10 to 15 db higher than the rms pressures to allow adequate reproduction of jet and rocket spectra (this would be a peak to rms pressure ratio of from 3.2 to 5.7).

The bank of sirens to be built at WADD approaches these requirements. The control over spectrum shape is not very precise with this source but certainly the spectrum can be varied. A difficulty with such a source is its expense since, to give a reasonable broad band simulation, it appears that at least five such sirens would be needed.

For general R and D work, the air modulated loud speaker appears to be the most feasible sound source. It can be very closely controlled as to frequency and noise level and, since the spectrum is controlled by an electrical input, it can be shaped

more readily than any other high intensity noise source. Eight such units (with controls) would cost about the same as two BBN sirens (with controls) and would provide an extremely flexible research tool.

IV D TEST METHODS AND SPECIMEN ARRANGEMENTS

Variations in test methods largely depend on whether design tests or proof tests are being performed, and even here there are many procedures that are similar. Whether proof or design tests are to be performed, a test SPL must be determined and some time limits established; the panel configuration must be established and a suitable mounting prepared; the orientation of the specimen to the sound field must be decided; the sonic load on the specimen must be known; and inspections must be made or some provision made to detect failure. In the case of design testing the additional step must be made for determining the dynamical and mechanical properties of the specimen (resonant frequencies, damping properties, multi-mode response characteristics, and non-linearity of response).

IV D-1. Determination of the Test Level

The first step is to determine the service acoustic load on the structure. This is done in several ways; if there has been a failure on a vehicle and design changes are necessary, then sound measurements can be made at the point of failure on the structure. If a prototype vehicle exists (or a full scale mock-up), sound surveys can be made at maximum noise levels, and if the vehicle is in a design state then estimates or calculations can be made from information on speed and power plant characteristics. Extrapolations are often made from the following types of existing data.

- (a) Curves of power spectrum level versus dimensionless frequency parameters for propulsion systems and model jets.
- (b) Plots of sound power level versus total jet stream power for rockets and for jets.
- (c) Diagrams of directionality patterns for existing engines.
- (d) Data on the overall level of boundary layer noise versus the vehicle Mach number (boundary layer noise has not been a significant cause of sonic fatigue failure).

- (e) Sound pressure spectra for various portions of the near noise field for various efflux velocities.

Once the service load on the specimen is established, then it is used to calculate a required test level. In the case of proof testing it is common to say that all the fatigue damage occurs when the engines are operating at full power with afterburners and that if over the life of the vehicle this condition exists for a total of (say) ten hours, exposing the structure to this environment on the ground for ten hours is a valid proof test. Another approach is to take the estimated mission profile of the vehicle and tabulate the number of hours the vehicle is exposed to various noise levels and then by use of Miner's cumulative damage rule, compute the number of hours the test structure must be exposed to full jet power to accumulate the same damage. This last approach requires a knowledge of the maximum stresses in the structure and the assumption of a statistical distribution of stresses to use the cumulative damage law. The gathering of the stress information requires panel tests and the procedure begins to take on many of the features of a design test.

There are several ways of establishing a design test level (see Section IV H) since the time of the test and the SPL will depend upon the type of analysis. One way is to determine the service SPL in a one cycle bandwidth at the panel resonant frequency then calculate a level that will produce the same damage in a short period (say half an hour) as the one cycle bandwidth SPL would produce throughout the service life. In some instances, an arbitrary SPL is set (say 160 db) and various panel configurations are tested and given a rank ordering as to their sonic fatigue resistance.

In general, the level and duration of a proof test and a design test are the two critical factors that show the worth of a structure and much of the analytical work in sonic fatigue design is directed toward calculating these two quantities.

It is usual in an aircraft development program that early design and proof tests are based on calculated service loads and then as mock-ups or prototypes become available, measurements are made to establish more precise operational sonic loads which

in turn are used to establish new design and proof test noise levels.

IV D-2 Configuration and Mounting System

Since no theory has been developed that will allow scale models to be tested for sonic fatigue and the results extended to predict the behavior of full size units, full size structures (or sections of structures) must always be tested. The main problem here is to reproduce the same boundary conditions on a specimen as would occur on the flight vehicle. If the boundary conditions on a test specimen are significantly different than they are on the vehicle, then the dynamical response characteristics of the specimen will be different and so will the fatigue life. When vehicle panels frame into bulkheads, this condition is often represented by bolting specimens to heavy frames for a test. To more closely approximate the stiffness characteristics of the bulkhead, mica gaskets are sometimes clamped between the specimen and the frame. This type of boundary simulation is often used even when the vehicle panel does not frame into a heavy structure; under such circumstances it is not very satisfactory and the practice of assembling several panels for a test (i. e. duplicating part of the vehicle) and making measurements on a central panel is to be preferred. The edge conditions of the panel of interest can, in this last case, simulate operational conditions quite well depending on the number of panels that can be assembled. This number is limited, to an extent, by cost considerations, but much more by the maximum size of specimen that the facilities can test. Most specimens tested are of the order of two by two feet but specimens three by three and larger can be tested in most of the test facilities and are to be preferred.

When open jet engine test stands are used for proof testing very large specimens (say 10 by 20 feet) can be tested.

Little can be said about panel configurations other than that almost all conceivable types have been tested - honeycomb panels, damped-panels, panels with Z stringers, panels with hat sections, structures with heat insulating material. It appears that honeycomb panels on a strength-weight basis are the most resistant to sonic fatigue,

but such matters are beyond the scope of this report.

IV D-3 Orientation of the Specimen to the Sound Field

From an examination of Table III Q it would appear that the facilities are about equally divided as to whether it is best to test the specimen at normal or grazing incidence. This would be a misleading conclusion, however, since it turns out that most of the facilities that have provision for both types of testing prefer to test at grazing incidence.

The advantages and disadvantages of these two methods can be summarized as follows:

1. Normal Incidence testing can give a higher panel loading for a given siren condition and chamber configuration. Since the sound is reflected from the specimen, the pressure at the specimen face will double (giving a 3 db increase in SPL). If the siren is operating at its maximum output and the additional three db is needed to run a test within an economical time period, such a test might be necessary. Unfortunately, the strong reflections from the specimen also help set up strong standing waves in the test chamber which can introduce large spatial variations in SPL and introduce considerable uncertainty as to what SPL is actually acting on the specimen. An examination of the data from the Convair, Fort Worth facility will illustrate this fact.

It should be noted that specifying a given chamber configuration is a somewhat artificial constraint and that if a given siren is attached to a narrow progressive wave chamber (say 6" by 36" in cross-section), noise levels as high or higher than in a normal incidence chamber can be obtained. The difficulty limiting the use of a very narrow progressive wave chamber is that the sound energy can be concentrated in such a small cross-sectional area that the energy taken by the specimen causes a large variation in SPL along the length of the specimen.

2. At normal incidence with plane waves it is only possible to excite symmetric modes of vibration (non-plane waves can excite asymmetric waves) while grazing

incidence can excite asymmetric as well as symmetric modes. It is important that a source be capable of exciting all modes in a specimen especially when the specimen has a multi-mode response.

3. When a panel specimen is tested normal to a horn face, coupled panel-horn resonances may be detected instead of a pure panel resonance.
4. In general, larger specimens can be tested at grazing incidence than at normal incidence because of the geometry of the chambers.
5. There has been a question as to which method best simulates operating conditions, and it is argued on the one hand that in service the sound is reflected from the ground to impinge normally on a surface, and on the other hand that the sound mostly grazes the specimen. Certainly no general approval or disapproval can be given to either method on these grounds, and in a sense, it is best not to ask the question in the form stated but rather to ask "how is the sound correlated in service and how might that correlation be reproduced or taken account of in testing."

It is readily apparent from the above list why testing at grazing incidence is generally preferred.

It is useful to carry the discussion of correlation mentioned in Item 5 a little further. Present facilities using siren sources with grazing or normal incidence cannot accurately reproduce the correlation functions that exist in a jet field. In the case of normal incidence the correlation will be close to unity at every point on the test surface. In the case of grazing incidence the correlation follows the properties of a simple wave, i. e. varying between + 1 and - 1 with the first zero crossing at the quarter wave point.

As shown in Section IV B-5 the correlation over a surface of the noise from a jet engine can be approximated by inclining the surface at some suitable angle to a plane wave. As has been mentioned, when the sound wave length is long compared with the panel dimensions, the question of correlation can be neglected. When this is not so,

however, it may be desirable to orient the panel at some angle to the progressive wave. The problem here is that the angle of incidence of the panel with respect to the sound field can cause other complications depending on the basic chamber design. If for example, we look at the data gathered at the Convair, Fort Worth facility, we see that the angle of incidence creates a variety of standing wave patterns in the chamber. Here the test rig for holding the specimen itself provides a good reflecting surface at any angle of incidence. If a progressive wave system were to incorporate ways of varying the angle of incidence of the specimen, it should also incorporate treatments of nearby surfaces to minimize sound reflections. It should be pointed out that more information on the correlation properties of jet and rocket noise has to be gathered before correlation properties can be usefully approximated (except in the crudest way) in routine tests.

IV D-4 Determining Sonic Loads and Specimen Response

From one to four microphones are used to measure the sound pressure level acting on the specimen during a test. They are usually spaced 1 to 3 inches from the face of the panel and the precise number used depends on the size of the specimen. Since a small change in db level corresponds to a large change in specimen stress, precise and frequent calibrations of the microphones and their associated electronic equipment are necessary and are usually performed.

From results of tests conducted by several of the facilities in determining sound field characteristics in their chambers it appears that variations in SPL of 6 db and higher can exist over the face of a specimen. If such a large variation existed during a test and was not known, considerable error would result so that it is important that measurements be taken prior to a test (with the specimen mounted in the chamber) to see if there is any significant spatial variation in SPL (perhaps the specimen position could be shifted or other steps taken to minimize any variation discovered). Four to six microphones could be positioned in front of the specimen to show whether the sound field was reasonably uniform or a traversing microphone could be used.

It is perhaps simpler to use the array of microphones since these can be

monitored during the test to check the sound field distribution and to give an accurate average of the SPL acting on the specimen. It is important that the SPL be accurately measured throughout the performance of any test.

Two to eight strain gages are used to determine the response of a specimen. The attempt is made to locate the gages at points of maximum stress, which points are selected by means of judgement, analysis or by the use of stress coat. A typical way of using stress coat is to coat the specimen and then resonate it with the siren at various frequencies at a low SPL or the specimen is sometimes excited by low level broad band sources (air modulated speakers or electrodynamic speakers). Although the gages usually get placed in areas of high stress they are rarely at a maximum stress, since the maximum stress usually occurs at a boundary where it is impossible to locate a strain gage. The gage location problem is important, for in many instances maximum stress values for use in design have to be extrapolated (or calculated) from these measured values, and if measurements are not made reasonably close to points of maximum stress, the extrapolations will be inaccurate (this is especially true with a non-linear response). In some instances the maximum stress is determined from a standard S-N curve by failing a specimen and then using the stress that corresponds to the measured fatigue life. Dividing this stress by the measured strain gage stress, gives a "stress concentration factor" or multiplication factor for that gage location (obviously this multiplier includes many more effects than the usual stress concentration factor). In general, most companies are somewhat vague as to how they insure that the measured stress is the maximum stress in the specimen (the stress used in S-N diagrams) or is proportional to the maximum stress by some known ratio, and inadequacies in establishing these values are a source of error in design.

Deflection pick-ups that rely on changes in capacitance or magnetic field are often used to measure the deflection of specimens. These devices are accurate to about one hundredth of an inch and have an advantage in that they are not attached to the specimen and cannot effect its response. They have the disadvantage that if the jig holding the specimen should deflect they will register this deflection as part of the panel

response. Also they have to be positioned prior to a test so that points of maximum deflection have to be determined (this is not too difficult, however). Deflection measurements are used primarily to determine panel resonances, as a check on strain gage data, and to give a picture of what is happening to the specimen.

Both stroboscopic lights and high speed motion pictures have been used in sonic design testing. By giving the designer a picture of the modal patterns in the specimen they permit more rational judgements to be made on design changes than would otherwise be possible (Martin, Baltimore found high speed motion pictures to be of considerable help in design). To take movies of every test might be time consuming but if access windows are available, stroboscopic lights should be used.

IV D-5 Inspection and Failure Detection

A specimen usually undergoes a factory inspection prior to a test and several periodic inspections during the test. Failure is detected by several means; unaided visual inspection, dye-check examinations, noting changes in natural frequencies, and noting changes in amplitude. A typical procedure would be to visually inspect a specimen prior to testing, stop the test for an inspection at 5 minute intervals up to 15 minutes and then inspect at 15 to 30 minute intervals thereafter. All during the test the resonant frequency would be monitored and if it shifted more than five cycles from the starting frequency, the test would be stopped for a visual inspection. Also the deflection might be monitored during the test. It can be seen that the most reliance is placed on the visual inspection and a failure is usually defined as a crack that can be seen with the unaided eye. Since this is how failures will, for the most part, be detected in service, it is a reasonable criterion. In the case where there can be internal failures (a honeycomb panel for example), this is often detected by the simple expedient of shaking the specimen to see if any loose pieces are inside, or by tapping the surface to see if the honeycomb structure has been damaged; large changes in frequency are always looked for. As a rule, internal failures are difficult to detect, and if such failures are found when the specimen is "opened up" after a test, it is often impossible to establish the time of failure. Dye-check has been used by Boeing, Seattle for detecting fatigue cracks. By this procedure,

hairline cracks can be observed that would otherwise be overlooked. A red dye is dissolved in a light oil of such viscosity and surface wetting nature that it is quickly sucked into any cracks when it is applied to a specimen. Excess dye is removed with a solvent and the specimen is coated with a white colloidal suspension (a developer). The red dye in the hairline cracks bleeds through the developer and makes the defect visible. This procedure can be used with a fluorescent dye in which case the specimen must be examined in ultraviolet light. The fluorescent dye is more sensitive and also more troublesome to use than the red dye and, to our knowledge, has not been used in sonic fatigue work on any routine basis.

When dye-check is used, fine cracks are detected much sooner than they would be with simple visual inspection. For example, the dye might indicate a crack after two hours of testing while simple inspection might not detect the crack until after three or four hours of testing. Dye-penetrant tests are time consuming and therefore more expensive than simple inspections.

Sonic fatigue failures are primarily a maintenance problem. Such failures are not critical in the sense that they are likely to cause the loss of a vehicle, and the principle motive for developing sonic fatigue resistant designs is that enormous amounts of money and time must be spent repairing and replacing damaged panels and sections. The balance, of course, is between any additional weight required to achieve a long sonic fatigue life (thus influencing the vehicle performance) and the maintenance time and effort required to keep the structure in proper repair.

Service failures, as we have mentioned, are detected primarily by visual inspections that are part of a routine maintenance check and this kind of inspection appears to be adequate for the present. Certainly it is not necessary to examine large sections of planes by any highly sensitive but time consuming crack detection techniques and unless SF failures are critical in nature it should not be necessary. Visual inspection is then an adequate method of detecting failures in aircraft SF testing, and while other more sensitive methods can be used, there does not appear to be any special advantage

to them. It is possible that SF failures in rockets could be critical (these are not maintenance problems) and, in these instances, sensitive detection techniques would be desirable for design and proof tests.

IV D-6 Determining the Dynamical Properties of a Specimen

The resonant frequencies are determined by exciting the specimen at a rather low sound level over the frequency range of interest (generally 50 to 1000 cps) and noting the strain response or measuring the panel deflection at each frequency. The excitation is usually by siren but standard loudspeakers or air-modulated speakers have been used. If there are several strong resonances in the panel, tests are usually carried out for each resonance and the one with the shortest life determines the life of the panel.

In those instances where multi-mode response is considered, rough correction factors for use in design are calculated from the stress response (at a given strain gage) at each of the resonant frequencies. It would be possible to develop approximate correction factors by comparing the stress response to a low level broad band excitation with the stress response to a low level discrete frequency excitation (at the resonance of interest) but this is not done at present. Several techniques are used to determine the damping factor and the response bandwidth at resonance of a specimen but these are variations on two methods. Either the logarithmic decrement of a specimen set into free vibration (say by a blow) is measured or the frequency response curve obtained with very steady discrete frequency excitation is plotted and measurements made at the half power points of the resonant peaks are used to calculate the damping.

In the first case, amplitudes of two successive peaks (X_n, X_{n+1}) are measured and the damping factor δ is calculated as $\delta = \frac{X_n - X_{n+1}}{2\pi X_n}$. This method is mostly applicable to calculating the damping of the first mode.

In the second method, once the response curve has been plotted (taking care to get accurate readings at the half power points of the peaks), δ can be determined from the fact that $2\delta f$ is equal to the measured bandwidth at the half power point (.707 maximum

stress), or it can be calculated by various formulas, the variables of which can be measured from the curve.

In general, determining the damping factor of a specimen is troublesome and when several measurements and calculations are made they often disagree so that it is good procedure to average the results of several tests for use in predicting specimen fatigue life.

To determine the non-linear response characteristics of a specimen it is excited at its resonant frequency by a discrete frequency siren and the stress responses at various sound pressure levels are plotted. The shape of the resulting curve shows the linearity of the specimen. Ways of correcting for non-linear response are discussed in Sections IV B-2, IV B-4, and IV H.

IV D-7 Combined Environments

There is very little work done with combined environments. As will be discussed in Section IV G, the set-ups are not elaborate and consist of high and low temperature tests in conjunction with a siren test (In a few instances vacuum boxes were used to apply a vacuum to the back of a specimen and this gave a combined temperature, pressure, and sound test). High temperature is produced by radiant heating and low temperature is produced by introducing carbon dioxide into an air stream behind the specimen. All combined tests that we know of have been proof tests and no attempts have been made to analytically predict fatigue behavior in service from short time combined tests.

IV E INSTRUMENTATION AND DATA ACQUISITION

From an examination of the facility descriptions it is apparent that most of the facilities have quite extensive arrays of instruments for control and data acquisition. Any variation between facilities is more in the nature of how they choose to make measurements rather than in the instrumentation.

The instrumentation in a facility consists of a control system for the sound source, a noise measurement and analysis system, a response measurement and analysis

system, and an instrument calibration system.

IV E-1 Sound Source Control Systems

In a jet engine installation the sound pressure level produced is controlled by varying the thrust, speed, air intake, and operating temperature of the engine. How this is done depends upon the particular design and model of the engine used. The control of the sound power output is very rough and the sound pressure level acting on a specimen is not primarily controlled by changing engine settings, but by measuring the sound field around an engine and locating the specimen in the field such that it is exposed to the desired SPL. As has been mentioned, the control settings on an engine may drift during operation (changing the SPL) so that it is customary to run tests for fairly long periods of time (several hours) to average out whatever fluctuations in SPL may occur.

The noise output of sirens can be far more accurately controlled than that of jet engines. The siren speed is controlled by electric motors or hydraulic motors and this speed, in the case of discrete frequency sirens, determines the sound output frequency. The amplitude of the sound pressure is controlled by varying the air pressure supply to the unit.

For discrete frequency tests the general requirements of the control system are that it (1) maintain a constant sound pressure level throughout the test, (2) maintain the frequency well within the response bandwidth of the structure being tested, and (3) be able to follow changes in the resonant response frequency of the panel if it should change due to non-linearity effects as the SPL on the specimen is increased.

Since a 1 db change in SPL represents a 12% change in pressure acting on a specimen, the sound level should be held within ± 1 db of the specified level. This should not be difficult in those facilities that control the SPL by feeding a signal back from the chamber to control the air pressure (a monitoring microphone in the chamber controls an electro-hydraulic or electro-pneumatic system that sets the air pressure into the siren). Unfortunately, except for a model of the recently developed BBN siren, no

measurements are available that give the variation in SPL of these sirens, and, although it is likely that they meet this specification, the fact should be checked.

There is little information on the variation in rms sound pressure level of broad band sources such as modulated air flow speakers and wide band sirens. Because of the electronic controls of the modulated air flow speaker it can probably hold steady within ± 1 db, but measurements have not been made on either unit.

The requirements on frequency control are determined by the response bandwidth of the test structure. Most aircraft structures are lightly damped and have Q's of between 20 and 30. If a structure has a Q of 25 then the bandwidth at the half-power point will be four per cent of the resonant frequency (at a resonant frequency of 100 cps the bandwidth would be 4 cycles and at 200 cps 8 cycles). If under these conditions the frequency of excitation were held only within $\pm 2\%$, the response power level could be half of what it should be and the stress could be less by 30%. Such variations would make the test extremely inaccurate and it is desirable to hold the stress at least within 10% which means a frequency control of about $\pm 1/2\%$. This is a minimum requirement on frequency control and, if possible, a smaller tolerance should be used. This is especially true if structures with Q's of the order of 50 or 100 are to be tested.

Convair, Fort Worth has excellent frequency control, ± 0.4 cps over the range 20 to 2000 cps, which gives a $\pm 0.4\%$ variation at 100 cps and $\pm 0.1\%$ variation at 400 cps. The WADD facility and the North American facility at Los Angeles are designed to meet the $1/2\%$ specification and no data is available on the other facilities. Frequency control is important and the limits of control should be known by the various installations.

IV E-2 Noise Measurement and Analysis Systems

There are about a dozen transducer systems available commercially for the measurement of high intensity noise (see pages 125-129, "Noise Reduction", Edited by L. L. Beranek, 1960 for a summary) but an examination of our facility descriptions

shows that most installations use Altec Microphone systems and one facility (Martin, Baltimore around 1955) has used Massa blast gages for measurements. Blast gages are more sensitive to vibration than most of the high intensity microphones and must be used with care.

Since the electronic equipment associated with the noise measurement and analysis is located in a sound insulated control room, it does not have to withstand high intensity noise and standard oscilloscopes, tape recorders, sound level meters, frequency analyzers, etc. can be used. The microphone is the only part of the system that must be especially selected for use in a sonic fatigue facility.

In the sound measuring system at least one microphone is usually monitored with a vacuum tube voltmeter or a sound level meter. The signals from a group of microphones are fed into a multi-channel tape recorder and stored on tape. The data may then be processed through frequency analyzers and graphic level recorders. At the present time when several microphones are used in measurement and the signals are analyzed, this is done to determine the character of the sound field, to check for uniformity or to see if anything unusual is happening. The present design methods do not provide for a non-uniform test load distribution and the best use that could be made of such information would be to calculate some kind of modified average pressure.

The analyses instrumentation presents the data in terms of peak value, rms value, and power spectral density, and these are usually automatically plotted. Many of the descriptions of the facilities contain lists of particular instruments that are used; they all do their job well and whether one uses a narrow band General Radio analyzer, a Davies analyzer or sets of Spencer Kennedy filters is mostly a matter of personal choice.

None of the test facilities are presently equipped to make correlation measurements but a few of them are in the process of building correlators (if correlation measurements are required it would not be an expensive task to gather the necessary equipment). The large WADD facility has provision for making such measurements and Lockheed has the equipment that was used in their study of jet noise correlation.

As was mentioned in Section IV B-5 when correlation measurements are made, they should be based on bandwidths that are representative of the Q's encountered with flight vehicle structures. This is necessary since the measured correlation is a function of bandwidth and is only an approximation of the "true" correlation over the structure.

In general, the noise measurement and analysis systems that are used in design and proof testing are more than adequate in all of the facilities visited.

IV E-3 Response Measurement

As has been discussed, strain gages and deflection pick-ups are used to determine the specimen response (accelerometers are not generally used because the additional mass they add to the specimen would change its response characteristics). The signals from the gages are monitored on VU meters, vacuum tube voltmeters, oscilloscopes, or recording oscillographs. The output from several gages is usually recorded on multi-channel recorders from which the information can be put on graphs either manually or by X-Y plotters. The output of the gages is usually displayed as a plot of stress or strain versus frequency that shows the resonant frequencies and can be used for determining the damping factor and the multi-mode correction factor.

In some instances the taped data is fed into peak counters to determine the peak distribution within various stress levels (over a short section of tape). Boeing, Seattle has done this as part of a design procedure while many companies have done it to see how closely the statistical distribution agrees with an assumed distribution.

Response data may be recorded by taking many samples (say in a ten hour proof test) or it may be recorded continuously during the test. The problem here is usually one of having far more data from a given gage than is needed, while not having enough gages on the specimen to give a good picture of the response.

The techniques used for measuring and monitoring response are standard, and, except for the problem of keeping the strain gages from failing before the specimen does,

none of the facilities have any difficulties.

IV E-4 Calibration Systems

Some facilities have their own calibration systems (anechoic chambers and standard microphones) directly associated with the sonic fatigue facility. Others rely on calibration from the general acoustic laboratory within the company or agency, or on having transducers calibrated at outside laboratories.

All of the facilities, before or after a test, go through standard system calibration procedures for the instruments or gages used. For example, General Radio calibrators and oscillators may be used to calibrate microphones and sound level meters while strain gages may be calibrated by the application of a precision voltage to each strain gage bridge. The techniques for calibrating systems and transducers are well developed and the importance of performing the calibration checks as well as periodically performing primary calibrations is well appreciated by all of the facilities visited.

IV F TIME AND COSTS

IV F-1 Cost of Facilities

Table III Q presents a summary of the information available on the construction and operating costs of the facilities. The construction costs vary over a wide range and one of the reasons for this, apart from variations in elaborateness, is that companies do not include the same items when computing their costs. Some companies include instrumentation — others do not, some include cost of building construction, others do not. Since many facilities were built as parts of existing plants and the buildings and much of the instrumentation already existed, while others were completely (or almost completely) new, this variation in computation method is to be expected. The construction costs in the table, therefore, have not too much significance beyond indicating very gross cost ranges.

A comparison of sound source costs is interesting because an examination of them and the figures in the table indicate that a fairly elaborate sonic facility (with a noise output between 20 to 40 thousand watts) including a large test chamber and ample instrumentation and almost any type of noise source can be constructed for about \$300,000.

BBN Siren — A single 24" siren and control system (acoustical output 25,000 to 30,000 watts) as manufactured by American Measurements and Control costs approximately \$50,000. The 12" siren with a 10,000 watt output costs about \$37,000.

Leonard and Rudnick Siren — From facility cost data we estimate the cost of a 36" siren (estimated output 15,000 to 20,000 watts) with controls to be \$22,000.

"In-House" Sirens — The perforated disc sirens cost about \$15,000 with controls.

Broad-band Sirens — A siren and control system of the type developed at the Aeromedical Laboratory generates about 25,000 watts and costs about \$22,000 with controls.

Modulated Air Flow Speaker — A single speaker with controls (2000 watt output) costs approximately \$5000 and ten units to generate 20,000 acoustic watts would cost between \$40,000 and \$50,000.

Array of BBN Sirens — To generate broad band noise at least 5 sirens would be needed and, assuming 24" units, these would cost about \$250,000 and have a noise output of 125,000 to 150,000 acoustic watts. Obviously a facility of this capacity is going to cost much more than \$300,000.

Jet Engines — Depending on the thrust, a jet engine costs between \$50,000 and \$100,000 and the noise output can vary from 10,000 watts to 100,000 watts (with afterburners). Convair, Fort Worth estimates the cost of a jet engine facility to be \$200,000 exclusive of the engine so that the complete facility could be built for \$300,000.

From the foregoing list it can be seen that most of the sources cost under \$50,000 so that whichever source is used in a facility it should not change the \$300,000 figure markedly.

IV F-2 Time and Cost of Programs

The operating cost (including overhead) of discrete frequency sirens, broad band sirens, or arrays of air modulated speakers in the acoustic power range 20 to 30 thousand watts is between \$50.00 and \$100.00 per hour while the hourly operating cost of a jet engine is in excess of \$500.00 (Douglas, Santa Monica, estimates the jet engine cost, including overhead, to be in excess of \$1000.00 per hour).

The \$30,000 an hour operating cost given for the large 4-engine half-wing facility at Boeing, Wichita illustrates the cost of building and testing full scale prototypes. This hourly figure undoubtedly includes substantial amortization or depreciation charges for the mock-up, but it indicates the cost range of full scale proof tests on prototype vehicles.

Most of the facilities reported a cost of between \$500.00 and \$700.00 to run a standard discrete frequency siren test on a specimen. This included applying the

strain gages, mounting the specimen, testing it and reporting the results; it did not include the specimen cost. A program involving 3 specimens would cost about \$3000 and take approximately two weeks to perform. Tests in a broad band siren or air modulated speaker facility would be about the same. If the three specimens were proof tested in a jet engine facility, the cost would be about \$15,000. These costs are only representative of tests on a fairly standard specimen, and if complex specimens are used, the figures will be much higher. For example, at Boeing, Seattle, molybdenum specimens (some with refractory coatings) used in the Dyna-Soar sonic test program cost between \$5000 and \$9000 each, and the sonic test itself was estimated to cost about \$1000 per specimen. When extremely expensive specimens must be tested, the operating cost of the test may be of minor significance and the development of a satisfactory structure by means of a minimum number of specimens may govern the choice of testing procedure.

The foregoing figures are mostly useful in that they document what is already widely known - that it is cheaper by a factor of 5 or 10 to run design tests in siren type facilities than to run jet engine proof tests. They emphasize the fact that there are large economic advantages to developing broad band sources such as the broad band siren and the air modulated speaker array for performing at least preliminary proof tests on structures, and show that whether discrete frequency sirens, broad band sirens, or air modulated speakers are used in a facility does not affect the costs significantly (for a given acoustic power output the discrete frequency sirens can give the highest SPL).

IV G COMBINED ENVIRONMENTS

IV G-1 Present Capabilities

Only a limited number of tests have been performed to assess the combined effects of high intensity noise and other environments such as pressure and temperature. Most of the facilities have not performed combined environment tests, and those that have done so have performed primarily proof tests. A brief summary of what has been done will illustrate this.

Boeing, Seattle has performed full life proof tests on panels subjected to vacuum pressure, high temperature, and high intensity noise. The specimens were mounted in a jig which was attached to a vacuum box that would apply a static pressure to the panel, and radiant heat lamps were positioned close to the panel. Specimen temperatures up to 2000° F. are shown in test data (not with sonic loads, however) and it is reported that temperatures up to 2700° F. can be obtained. When combined pressure-temperature-noise tests are performed, the heating lamps are positioned about 1 inch in front of the panel and in the siren stream; when only temperature tests are performed, the lamps are positioned in back of the panel away from the direct siren stream (the sonic test is performed at normal incidence). Surface temperatures are measured with radiation pyrometers, conventional thermocouples, and quartz covered contact thermocouples, and the panel response is measured with contacting deflection pick-ups; strain gages are not used in the combined sonic-temperature tests. Apparently during these tests the specimens could be heated without difficulty and no special precautions had to be taken to prevent the siren air from impinging on the specimen. From an examination of Figure III A-14 it can be seen that for this particular test program the maximum temperature specified with a sonic load is about 1280° F. at an SPL of 136 db (a rather low SPL), and it is probable that if a high noise level were required and large quantities of siren air were passed over the specimen, it would be difficult to maintain high temperatures without air shielding devices being used.

The vacuum box, it should be noted, can be pressurized to impose a

positive pressure on the back of the specimen rather than a negative vacuum load.

These tests are duplications or simulations of flight environments and are simple "go", "no-go" tests. Specimens are built and tested until one lasts the number of minutes it has to endure this environment in flight (or perhaps a few minutes more as a safety factor), and there is no rational design procedure involved that would allow the specimen's behavior to be predicted in other environments (say, a higher noise level or higher temperature).

Convair, San Diego has performed SF tests on panels at temperatures that range from -67° F. to 600° F. These temperatures are obtained by introducing CO_2 gas into a box at the back side of a specimen or using electrical heaters to warm the specimen (by heating the air in the box and by radiation). Little is known about the tests other than that they were proof tests to check the effects of temperature on bonded structures.

North American, Columbus; North American, Los Angeles, and NASA, Langley Field have all made provisions for electrical power to allow radiant heating of SF specimens, but none of them have performed combined temperature - SF tests (NASA has made some sonic tests with pressurized specimens). Both North American facilities have also made arrangements for performing combined vibration shake table and sonic fatigue tests in their installation. These are all plans for the future and no tests have yet been performed.

It is clear from this summary that not much money has been spent by any facility for equipment to perform combined tests (we are speaking only of tests performed in conjunction with sonic fatigue work) and that if combined tests of any magnitude were required, the necessary facilities would have to be constructed.

IV G-2 What Environments are Important

Before the question of whether combined tests are necessary can be considered, it is desirable to list those environments or operational conditions that can affect the sonic fatigue life of a structure and perhaps consider how they influence the life.

Temperature

This is a critical factor in the sonic fatigue life of a structure and can

influence it in several ways (see Figures IV G-1, IV G-2, IV G-3).

- (1) The S-N curve of a material changes with the temperature thus changing the fatigue properties of the structure.
- (2) The elastic modulus changes with temperature so that the dynamic response of a structure will change, thus modifying the fatigue life. (For example, the elastic modulus of stainless steel decreases by a factor of 3 as the temperature goes to 1500° F.)
- (3) The internal damping characteristics of a specimen can vary with the temperature, thus changing the fatigue life.
- (4) The creep or plastic yield properties will vary with temperature. This should not have much of an effect on the SF characteristics of a structure since the fatigue is caused by dynamic loads that are continually reversing in sign. Creep would change any static stresses in the specimen and to this extent would affect the fatigue.
- (5) High or low surface temperatures on a structure can induce thermal stresses or strains that can change the fatigue life.

Pressure

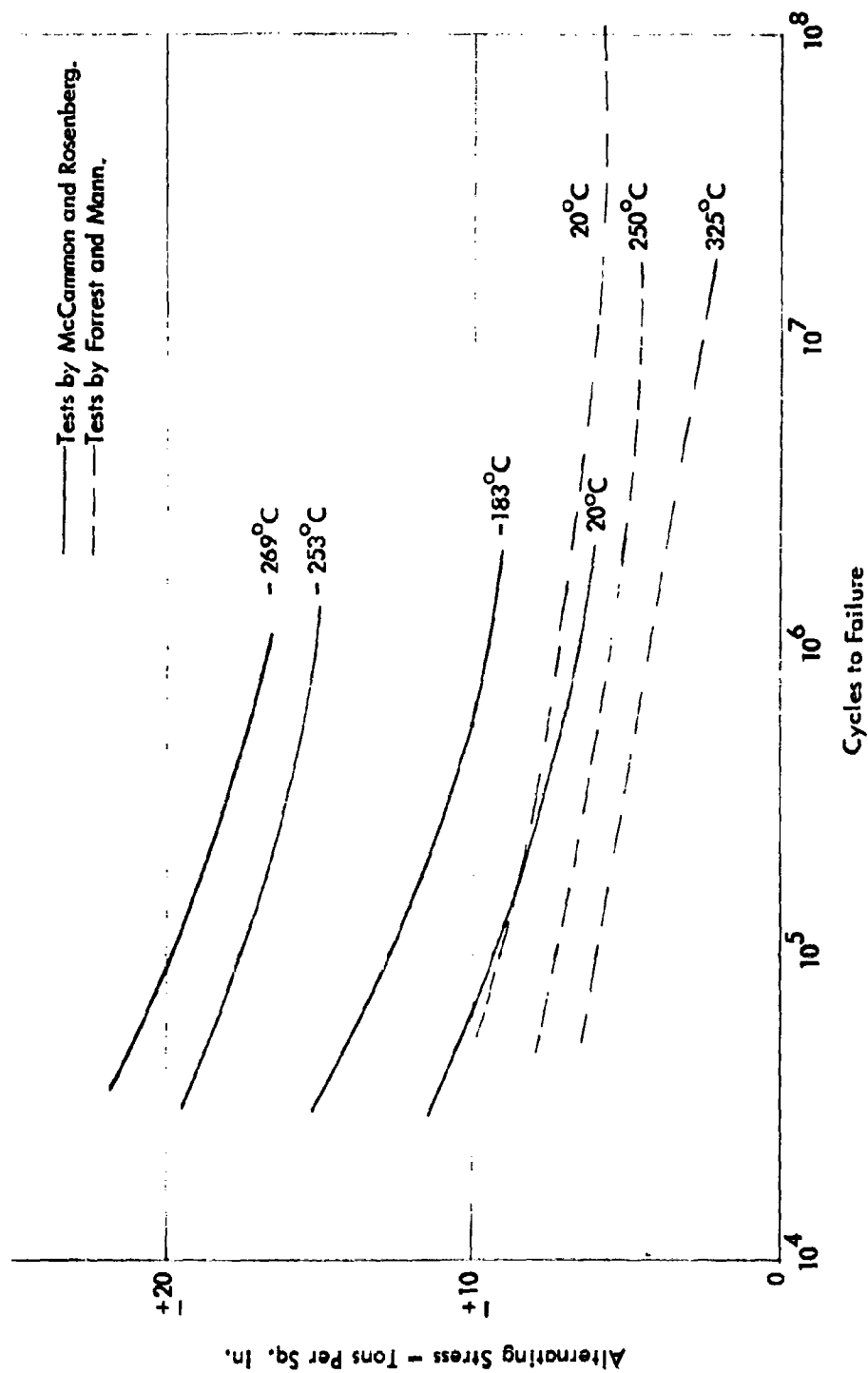
A pressure difference across a panel can affect its fatigue life in two ways

(1) the fatigue stresses will be superimposed on the static stress associated with the pressure and this (as is known from the Goodman or Soderberg diagrams) will cause failure at a lower alternating stress and (2) the dynamic response characteristics of the panel can be changed.

Corrosive Atmospheres

Corrosion can reduce fatigue life in several ways: (1) there can be a roughening of the surface thus introducing many stress raisers, (2) the thickness of a panel can be reduced, and (3) in the case of continuous corrosion with repeated stressing (as occurs in sonic excitation) the corrosion occurs in the fine cracks after their formation and greatly hastens the ultimate fatigue failure of the structure ("corrosion fatigue").

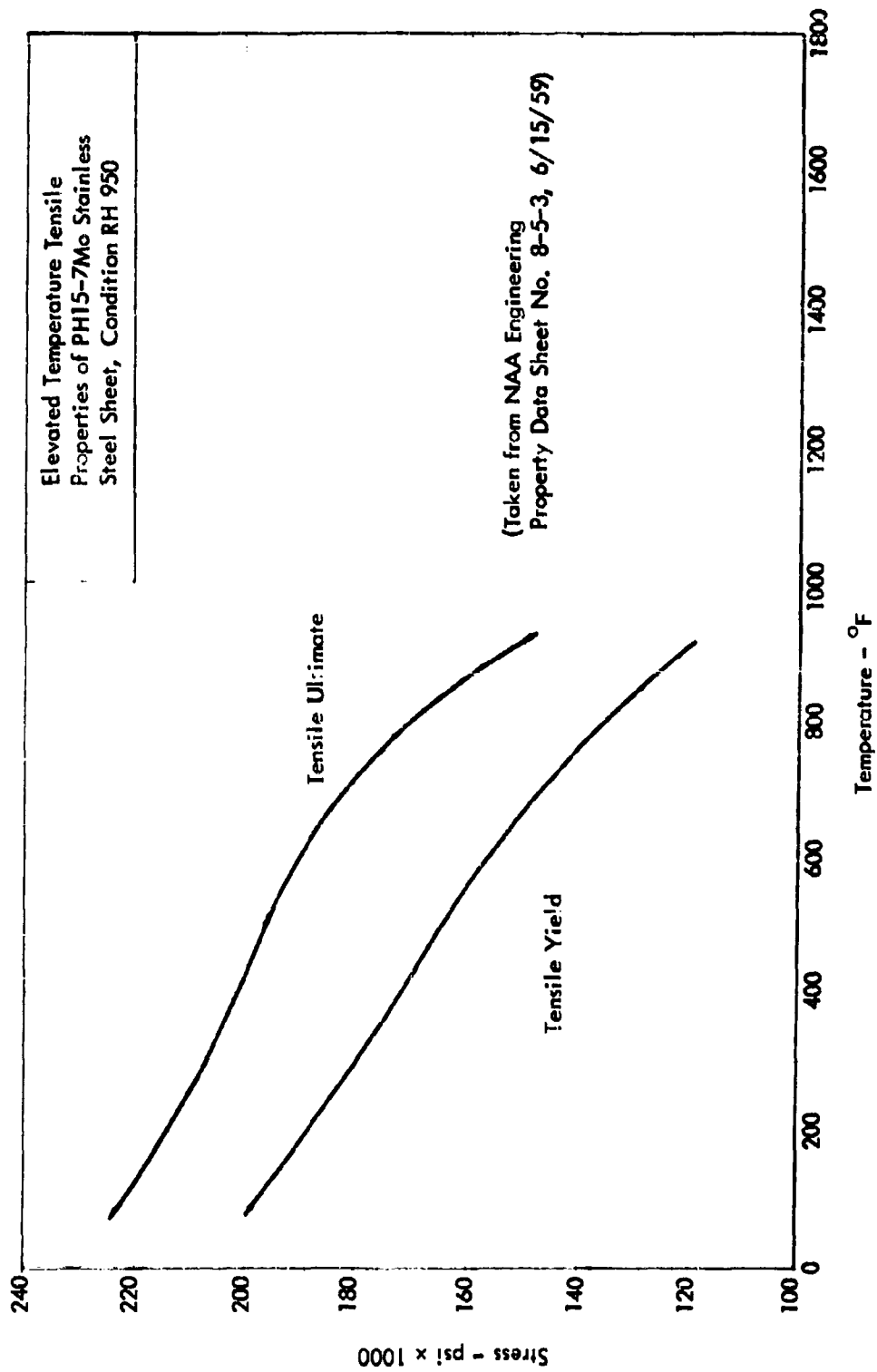
The published literature on the effects of corrosion on fatigue, although scanty, indicates that the effects of corrosion can be very important. For example, Jackson, Grover, and McMaster in "Advisory Report on the Fatigue Properties of Aircraft



INFLUENCE OF TEMPERATURE ON THE
S-N CURVE FOR COPPER

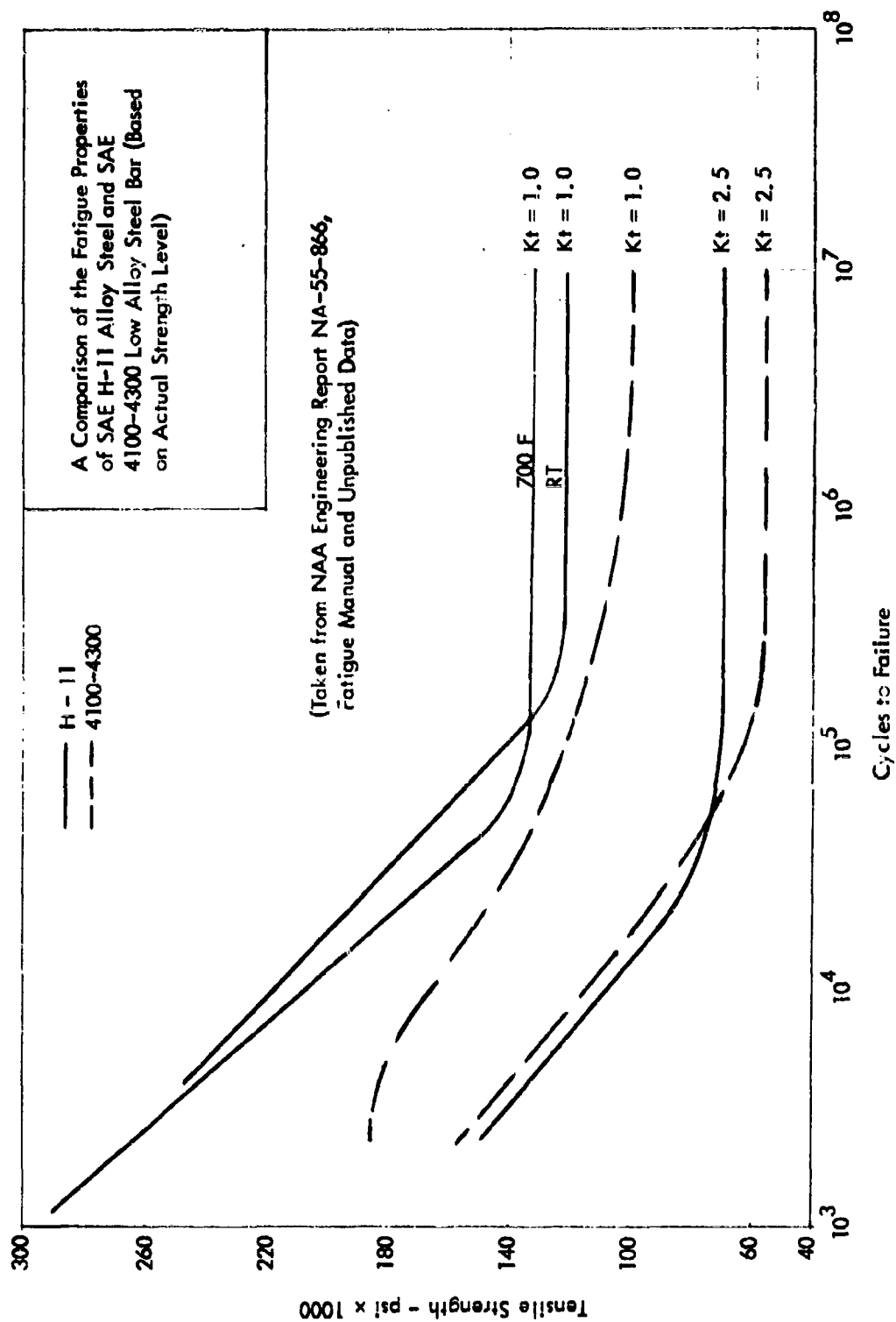
(Taken from: "International Conference
on Fatigue of Metals", 1956, Session 4,
Paper 1 by N. P. Allen and P. G. Forrest)

FIGURE IV G-1



ELEVATED TEMPERATURE TENSILE PROPERTIES OF PH15-7 Mo STAINLESS STEEL SHEET

FIGURE IV G-2



(Taken from NAA Engineering Report NA-55-866,
 Fatigue Manual and Unpublished Data)

A COMPARISON OF THE FATIGUE PROPERTIES OF TWO STEELS

FIGURE IV G-3

Material and Structures" OSRD Report No. 6600 (Mar. 1, 1946) present a graph that shows that when a Duralumin sample is corroded by being immersed in salt water for 18 hours before testing, the fatigue strengths are reduced to about 2/3 of their uncorroded value. It has also been found that in most cases a severe corrosion prior to an endurance test is much less damaging than a slight corrosion which takes place simultaneously. Tests by Dolan (ASME Journ. of Appl. Mechanics, 1938 page A141) with tap water running over a specimen show that the stress concentration factor for corrosion (endurance limit in air divided by endurance limit of same specimen in water) is highly dependent upon the material and for one material, a chrome-nickel 3140 steel, ran from about 3-1/2 to 7. On the basis of limited tests it appears that certain materials such as some stainless steels and bronzes have only a small reduction in fatigue strength under corrosive conditions. The influence of frequency upon corrosion fatigue and also the effects of discontinuous loading such as occurs in aircraft service are not known.

Flight Loads

Flight loads on panels are of two types, pressure loads normal to the panel and axial loads imposed upon the panel by the straining of the aeroplane structure. Stresses set up by these loads can influence the fatigue and, in the case of thin panels, the stiffness characteristics can be altered.

Structural Vibration

While in principle non-sonic vibrations transmitted to a panel via the primary structure of the vehicle or perhaps other panels will contribute to its fatigue, in practice this contribution will be small and most likely negligible. Certainly a panel exposed to a high intensity noise field will receive most of its excitation from the field and whatever excitation is received from adjacent panels will be due to the vibration of those panels in the sonic field. Most vibration transmitted via the primary structure will have an energy content that is orders of magnitude lower than the acoustic excitation.

Nuclear Radiation

Flight vehicle structure might be exposed to nuclear radiation from two

sources, (1) a nuclear power plant or (2) radiation from the upper atmosphere or outer space. In general, structural metals are negligibly affected by space radiation while organic materials can be affected only by very long exposures. The source that could have the greatest influence on material is the nuclear power plant and even here the metals are not greatly damaged. Table IV G-1 lists some of the material effects that can be expected from fast neutron bombardment. Values in the upper part of the table (say above 10^{18}) could be obtained only by being in a reactor or by direct contact with radioactive sources. As can be seen the metals can withstand thousands of times more radiation than organic materials.

Not many tests have been made on some of the characteristics of metals after exposure to severe radiation but on the basis of available test information the following trends are noted. *

- (1) Yield strength can increase up to 450% for annealed and to a lesser extent for cold-worked metals.
- (2) Tensile strength can increase up to 75% for annealed and to a lesser extent for cold-worked metals.
- (3) Ductility can be decreased one-fifth to one-third on the average for annealed and to a lesser extent for cold-worked metals.
- (4) The elastic constants show no change according to limited data.
- (5) The work hardening decreases.
- (6) The creep rate is usually unaffected.
- (7) The fatigue strength is unaffected according to limited data.
- (8) The damping capacity and internal friction is unaffected according to limited data.

*Taken from REIC Report No. 5, "The Effect of Nuclear Radiation on Structural Metals", by Allen, Wolff, Elsea, and Frost, May 31, 1958, ASTIA-AD 157 170

n/cm^2	Material	Effects
10^{21}	Stainless Steels and Aluminum Alloys	Ductility reduced but not greatly impaired.
	Stainless Steels	Yield strength trebled.
10^{20}	Ceramics	Reduced thermal conductivity, density, crystallinity.
	All Plastics	Unusable as structural materials.
	Carbon Steels	Severe loss of ductility, yield strength doubled.
10^{19}	Polystyrene	Loss of tensile strength.
10^{18}	Hydrocarbon Oils	Increase in viscosity.
	Natural Rubber	Extensive changes, hardening.
10^{17}	Polyethylene	Loss of tensile strength.
	Butyl Rubber	Extensive change; softening.
	Organic Liquids	Gassing of most stable ones.
10^{16}	Natural and Butyl Rubber	Loss of elasticity.
	Water and least stable organic liquids	Gassing
10^{15}	Polytetrafluor-ethylene	Loss of structural strength.
10^{14}	Germanium Transistor	Loss of Amplification.
	Glass	Coloring.

(Taken from WADD TR 60-785, Pt. 1, January 1961, "Hyperenvironment Simulation", by T. M. McCoy)

MATERIAL EFFECTS FROM FAST NEUTRONS

TABLE IV G-1

Only limited tests have been performed on structural adhesives but they indicate that there is a loss of strength with increased radiation (especially if there is an increase in temperature). *

There is one important fact that must be emphasized here. All the metal and plastic properties that have been discussed were measured after the material had been exposed to a radiation source. Combined tests could not be run. There is a question of whether the results would be different if say the damping properties were measured during the radiation exposure; this is not known however, and the data available pertains to tests that have been conducted serially.

IV G-3 Necessity of Combined Environment Testing

When the present sonic fatigue testing techniques are considered in conjunction with the possible effects that other environments can have on fatigue life, several conclusions can be drawn. Before discussing these conclusions it is well to emphasize the non-critical nature of most sonic fatigue failures; the fact that SF is mostly a maintenance problem; that cost is the great determining factor in sonic fatigue testing, and that reasonably satisfactory SF designs have been obtained without combined tests. It is against this background that decisions regarding combined tests must be made.

(1) A combined test is the only way to assess the fatigue effect of high intensity noise and high temperature on a structure and the effect can be very severe.

When all the properties that change with temperature in a metal are examined, it becomes apparent that when considering the sonic fatigue of a specimen at two different temperatures, it is as if one were dealing with two different materials. The S-N curve is

*See REIC Report No. 3, "The Effect of Nuclear Radiation on Elastomeric and Plastic Materials", by Broadway, Youtz, Zaring, and Polinchak, May 31, 1958, ASTIA AD 149 552

different, the elastic constants are different, and the damping is different.

Since the present methods of designing and testing for sonic fatigue involve the experimental determination of many of these properties or of structural characteristics that depend upon them (the resonant frequency of the panel, the deflections or stresses, the damping, and the non-linear stress load response), the test specimen must have essentially the same characteristics as the in-service structure, otherwise the test means very little.

There are no analytical techniques currently available that will permit tests to be run at room temperatures and then extend the results to predict with some reasonable accuracy what will happen at much higher temperatures.

(2) The effect of combined noise and pressure can be determined only by a combined test and, in some cases, pressure can have a large effect.

Some very limited tests performed at NASA, Langley Field showed that the life of a curved panel was increased by a factor of two when a pressure of approximately 6 psi was applied. In this instance, the application of pressure lifted the panel and relieved some stress concentration areas. The application of pressure to a flat panel will affect its non-linear response characteristics and it is not possible to say what relationship the pressure has to the fatigue life so that if large pressure differences are expected across a structure, some combined tests should be performed.

(3) In general, not much is known about the quantitative effects of corrosion on sonic fatigue nor is the service corrosion environment of most vehicles well defined. Corrosion fatigue can be serious, however, and if an unusual operating environment is expected and corrosion might be a problem, then a simulation of corrosion should be included in the tests.

To our knowledge there has been no attempt to include the effects of corrosion in the sonic fatigue tests. * The effects of corrosion of the surface can be

*During some in-cell jet engine proof tests that Boeing performed on the B-52 (Test No. T2-1155) the sonic fatigue specimens were sprayed with a water mist to keep them from overheating. Since the tests lasted for several hours, some corrosion fatigue may have occurred during this process.

represented by soaking the specimen in a corrosive liquid such as salt water, for a period of time prior to the testing. However, the conjoint effect of corrosion and fatigue representing service conditions where both occur simultaneously can only be represented by a combined test. This might be accomplished by introducing a spray into the test section of the chamber or over the specimen during a jet engine test. The question is whether tests as currently performed are of a sufficiently long duration to allow corrosion fatigue to be assessed.

It should be mentioned that if combined design tests are considered, then the S-N curves used in the analysis must be corrosion fatigue curves. That is curves developed from fatigue tests performed under corrosive conditions.

(4) The effect of flight loads on sonic fatigue life can only be assessed by combined tests. Only in situations where flight loads are quite different than those experienced in the past should such tests be considered.

Although the effect of flight loads on sonic fatigue can only be determined by combined tests, the fact that the present methods of design can give configurations that have maintenance - free lives of reasonable length and that these methods do not consider flight loads, indicates that such loads may not have significantly influenced the results. Whether this will be the case in the future, it is difficult to say. At the present time, however, it does not appear necessary to carry out combined tests with flight loads. It should be emphasized that the methods of performing such combined tests are not at all clear. The membrane, axial stresses, or shear stresses induced by flight loads might be reproduced by stressing one side of a specimen when it is mounted in a test jig or the stresses induced by normal loads might be simulated by pressurizing the specimen (varying the pressure throughout the test). These methods would only give a gross approximation to flight loads and how a reasonable simulation could be made is obscure (loading pads such as are used in standard aircraft fatigue tests can not be used because they would completely change the response characteristics of a specimen).

(5) At the present time, if there is considerable structural vibration in addition

to sonic vibration in a panel, the combined effect can only be determined by a combined test. The possibility of non-acoustically induced vibrations significantly affecting the fatigue life of a panel is small, and combined tests are not necessary.

While structural vibration in conjunction with sonic excitation may be important in evaluating the behavior of electronic components or instruments, a structure that is in danger of sonic fatigue failure will not, in general, be subjected to non-acoustically induced vibration that could significantly affect its fatigue. While such vibration can be approximated by vibrating a specimen with a shaker, there does not appear to be any necessity for such a combined test.

(6) Published information on the effects of nuclear radiation on material strength indicates that it is extremely unlikely that combined radiation and SF tests will be required.

All available information on the effects of radiation on fatigue life has been gathered by serial tests and shows that metal fatigue life is substantially unaffected by such radiation. There is no test information to show that simultaneous irradiation and cycling alters the fatigue life, so that elaborate and expensive combined tests in a modified SF facility would be unjustified unless more basic work were to show that simultaneous testing could give results quite different from serial tests.

If radiation is a significant operating environment for a vehicle, sonic tests can be performed after exposing the specimen to a radioactive source or, since bonding material or organic honeycomb structures are the only likely components to cause trouble, the strength properties of these materials after radiation exposure could be simulated in the specimen (a material of the same adhesive strength as the post radiation strength of the standard bonding material could be used in the panel fabrication). It might also be possible to expose the bonding material to radiation prior to constructing the specimen, although changes in other properties might make this difficult.

IV G-4 Use of Facilities for Combined Environment Testing

The existing facilities can be used for performing temperature and sonic fatigue design tests. Radiant heating or resistant heating can give temperatures between

1000° F. and 2000° F. in combination with sonic loads, and strain gages that operate in the 1500° F. range are commercially available so that current design procedures can be followed. Running SF design tests at high temperatures will be a time consuming and expensive procedure (mainly because of the difficulty of using strain gages at elevated temperatures) and, in addition to performing the tests, S-N curves of the material at the operating temperature must be determined for use in the design calculations. The scatter in S-N curves at elevated temperatures is higher than in standard S-N curves and the cumulative damage rules are even less reliable* so that the design results will be more approximate than they are for room temperature tests.

No facility is presently equipped to conduct large scale temperature and SF proof tests and it is questionable whether such tests would be necessary. A comparison of rather small scale proof tests (say a 5 foot by 10 foot section of structure tested in a jet engine or equivalent broad band field) made with combined environments and similar tests made with noise only should provide a reasonable basis for estimating sonic fatigue life of the vehicle (from full scale proof tests performed at room temperature) and the additional knowledge gained with full scale combined tests would not be worth the considerable expense and effort involved.

Tests that involve pressurizing a specimen could be carried out in any of the facilities. Such a test would be to simulate pressure loads or possible flight loads. Full scale tests can be performed by pressurizing or evacuating the vehicle. Such procedures are quite straightforward and do not involve highly specialized equipment.

Two of the facilities have made provision for performing combined sonic and non-acoustically induced vibration tests. While these tests are useful for electronic components, they are not necessary for structural sonic fatigue tests.

None of the facilities have any capabilities for performing nuclear radiation

*Cumulative Fatigue Damage at Elevated Temperature" by W. Rey, September 1958, NACA TN 4284

tests with SF and are not likely to acquire such capabilities in the immediate future. As has been mentioned, such combined tests do not appear necessary and if radiation is a problem, tests can be performed on specimens that have been exposed to radiation.

IV H RECOMMENDED PROCEDURES FOR A FACILITY USED AS A DESIGN TOOL

Much of the theory and equipment used in sonic fatigue design has been discussed and evaluated and we should now like to outline a design procedure that is based on the methods used by Douglas and Convair, Fort Worth (with some variations) to illustrate in some detail the most promising design approach currently available for use in siren facilities. This presentation should be useful in showing the many approximations and judgements required to interpret the results of design tests and should give some insight into the problems involved. It will also give some insight as to why proof tests are required.

The design and development of a panel or structure involves the following broad steps.

1. Determination of the sonic loads or environment.
2. Development of a preliminary specimen design or configuration.
3. Fabrication of specimen and determination of its dynamical characteristics.
4. Calculation of an acoustical test load for the specimen.
5. Sonic fatigue test of the specimen.
6. Calculation of the fatigue life the specimen would have in a given acoustic environment or the most severe acoustical environment the specimen can withstand for a given time period.

A comparison of these last figures with the vehicle requirements will show whether the structure is satisfactory or whether a re-design is required.

IV H-1 Determination of the Sonic Loads

Estimates must be made of the spectrum level at various locations on the vehicle. When the vehicle is in the preliminary design stage, use must be made of empirical relationships based on data that is available on existing engines and rockets, theoretical analysis, and model tests. In general, these predicted sonic loads are not very accurate and as soon as prototype vehicles or mock-ups are available, measurements should be made and corrected sound levels used in the design procedure.

The following listing illustrates the kind of information that can be used

for predicting sonic loads and the bibliography at the end of the section gives reports that are useful for estimating such loads.

1. Near and far field measurements of constant SPL contours of propulsion systems and model jets.
2. Near field measurements of constant SPL contours along vehicle structures of rockets and jet aircraft.
3. Power spectrum level/vs dimensionless frequency parameters for propulsion systems and model jets.
4. Plots of sound power level vs. total jet stream power for rockets, turbojets (with and without afterburner) air jets, and model jets.
5. Measured power spectral density as measured at different locations on vehicles.
6. Tabulations of errors in the prediction of near field acoustic loads showing the method of prediction, the error in decibels, and the error in percent.
7. Comparisons of measured and estimated pressure levels of existing vehicle structures.
8. Comparisons of mathematical expressions of inverse square loss to actual measurements of SPL at various distances along vehicle structures.
9. Data on the overall level of boundary layer noise vs. vehicle Mach No. (comparison of estimated levels with available data).
10. Empirical relationships between free stream dynamic pressure and overall external SPL of boundary layer noise measured by various experimenters.
11. Examples of sonic exposure as a function of the vehicle and its mission profile.
12. Correlation measurements of jet noise and model jets.
13. Sound pressure spectra for various portions of the near noise field for various efflux velocities.
14. Sound level contours as compared to vibration level on specific aircraft structures.
15. Comparison of amplitude of vibration response with amplitude of acoustic excitation on specific aircraft.

Acoustic models have been used to predict the environment of the B-58 by Convair, Fort Worth. A one-twelfth scale model of the vehicle was used to determine the jet engine noise distribution on the airframe, and it was reported that the predicted

values compared favorably with measurements made subsequently on both flight test and production B-58 airplanes.

At present no one makes use of the information available on correlation measurements on engine and model jets. As was discussed in Section IV B-5, the directionality patterns of the sound field can often be used to calculate the direction a plane wave must travel in order to approximate the correlation effect of the sound on a panel. If actual measurements are not available on the sound field distribution, only very crude estimates can be made of the angle this fictitious plane wave front makes with the specimen.

IV H-2 Development of a Preliminary Specimen Design

The panel type or structural configuration is usually determined by design considerations other than sonic fatigue (flight loads, for example) so that the problem is one of assessing the effects on this structure of the sonic loads that have been determined. An analysis of the design can be made but so many assumptions have to be made about stress concentration factors, damping factors, and boundary conditions (also non-linear or multi-mode response must be guessed at or neglected) that the results are usually of little value. Currently, the best way to assess a design that is still "on the drawing board" is to compare it with past designs that have withstood known acoustic excitations. As can be seen from Section III, numerous programs have been undertaken to develop structures for specific application in high intensity noise environments. Reports on the results of these programs show that a variety of designs have been built that have withstood high noise levels, and some general principles of design and design hints have been established. All this past information can be used to make comparative evaluations of the types of structures that can be used for given noise levels, and can give a rough indication as to whether the new design might or might not be satisfactory. Once a panel configuration has been established that appears to be satisfactory, then several specimens must be fabricated for testing, and the real evaluation of their sonic fatigue life begins.

IV H-3 Theory of Analysis

Before proceeding with a discussion of siren design testing it is desirable to

outline the assumptions and theories that form the basis of such testing rather than to develop them piecemeal during the description.

The problem of determining the fatigue life of a structure can be broadly divided into the problem of knowing maximum stresses that exist and knowing how those stresses determine the fatigue life. The stress tests are performed primarily to determine the first quantity, the maximum stresses that will be induced in a structure by a given sonic excitation. The fatigue life can then be calculated from standard S-N curves by use of a cumulative damage law and by use of some assumed statistical distribution of stresses.

The first problem is to relate a stress measured in a discrete frequency field to a stress that will be induced by a random field. This is done as follows:

Miles gives a mean square response of a single degree of freedom under a

$$\text{random excitation as } \sigma_r^2 = \frac{\pi}{4\delta} f_o \sigma_o^2 p_r^2$$

where

σ_r = rms stress under random loading

δ = damping factor

f_o = resonant frequency of panel

σ_o = equivalent dynamic stress/unit load for the mode shape at zero frequency

p_r = rms sound pressure in a one cps bandwidth of the random excitation (spectrum level)

$$\text{The expression for a sinusoidal excitation is } \sigma_s^2 = \frac{1}{4\delta^2} \sigma_o^2 p_s^2$$

where σ_s = rms stress under sinusoidal loading and

p_s = rms sound pressure under sinusoidal loading

From the above, the rms sound pressure required to give the same rms stress response in a sinusoidal noise field as that in the random field becomes: $p_s = p_r \sqrt{\pi \delta f_o}$.

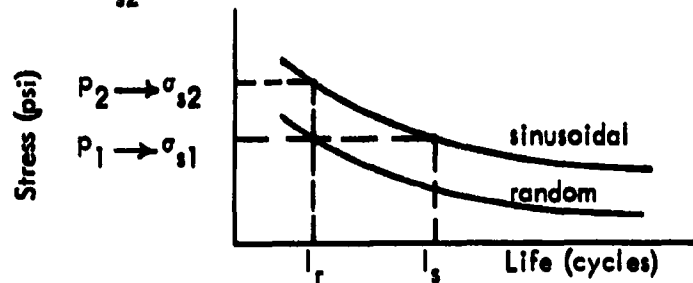
If the specimen has only one significant mode and has a linear response the above equation can be used, but since this may not be the case, correction factors must be placed in the equation. Then:

$$p_s = AB p_r \sqrt{\pi \delta f_o}$$

Where A is a correction to account for the fact that the panel may respond in a non-linear way so that the stresses will not be directly proportional to the load, and B is a correction to account for any change in stress due to the panel responding in more than one mode (there could be two or three modal deflection patterns superimposed on one another to give a high stress). These factors will be discussed later and the above equation is only to illustrate the characteristics of a panel that must be determined to calculate its fatigue life.

We now have a formula that can give a siren test level that will produce the same sinusoidal rms stress as the random rms stress produced by a given acoustic field. While it produces the same rms stress it does not yield the same life as the service environment. A siren test level that will produce the same fatigue life can be found as follows:

Referring to random and discrete frequency S-N curves* quoted in terms of rms stress, let a siren pressure p_1 produce the common rms stress σ_{s1} , which yields lives l_r and l_s . To obtain a common life l_r the given pressure must be increased to p_2 yielding a stress σ_{s2} .



*The random S-N curve is constructed from a discrete frequency S-N curve by assuming a Rayleigh distribution of stress peaks and accumulating the damage according to Miner's linear damage rule. The stress referred to in the random S-N curve is the random rms stress.

At this point there is now available a siren test level which would duplicate the fatigue life in the service environment; the common duration of the siren test and the service life, however, would be very long, and it is desirable to accelerate the testing to a point where it can be accomplished with a reasonable expenditure of time and money. A new (accelerated) test level is chosen by moving along the abscissa of the sinusoidal S-N curve to a fatigue life corresponding to an acceptable test duration (one or two hours) and increasing the siren test pressure by an amount sufficient to produce the corresponding increase in stress. This usually results in such high pressures and structural deflections that the relation between excitation and response is significantly non-linear, consequently a new correction factor A has to be used.

The value of the siren level is now such that, if the structure successfully endures the accelerated test, it should last the required time in the service environment.

This is the theory used in siren tests. Douglas has reduced much of the above information to nomograph form for ready use, but the procedures are essentially the same. The main difficulty with using the theory is trying to determine values to put into the formulas - what is the maximum stress in the panel, what is the damping factor, what is the multi-mode correction factor, what is the non-linear correction factor, and this is quite apart from such considerations as the accuracy of Miner's cumulative damage rule. In spite of the difficulties, reasonable results can be obtained in many cases, and it is considerably cheaper than running jet engine tests.

IV H-4 Determining the Dynamical Properties of a Panel

Discussions in previous sections give some ideas of the difficulty of preparing a specimen such that the boundary conditions closely simulate the actual boundary conditions of an integrated structure. In the case of large simple spans, mica gaskets or other suitable gasket materials can be used at the mounting frame to relieve any stress concentrations that would cause an unrealistic failure at the joints. The difficulty of duplicating boundary conditions is most effectively alleviated by using as many sections

of the structure in a specimen as possible. Some facilities have constructed test specimens of such a size that only 20% of the total area was considered to be the actual section under test, and certainly as large a specimen as possible should be used.

When the specimen has been mounted, strain gages must be located and the resonant frequencies, modal response characteristics, damping factors, non-linear response characteristics, and stress concentration factors must be determined.

Using electro-dynamic speakers, air modulated speakers, or sirens as a source, the specimen is excited (at a relatively low level) to determine the resonant frequencies and mode shapes. If it has previously been determined that the correlation is important, it is possible to more closely simulate this property by varying the angle between the test specimen and the impinging sound, otherwise grazing or normally incident energy can be used. The mode shapes may be investigated with the use of strobe lights or high speed motion pictures (2000 to 4000 frames/sec.).

For simple panels, judgement and calculation may be used to locate strain gages, while for complex panels the use of stress coat is recommended to find areas and direction of high stresses. This must be done for each major resonance. In general, 4 to 8 gages are required to give a good representation of stress at the critical areas. Since usually a gage will not be located at a point of maximum stress, at some later stage in the proceedings a relationship must be established between gage stress and the maximum stress referred to in the S-N diagrams.

As was discussed in Section IV D-6 there are several ways of determining the damping factor and response bandwidth at resonance, and since because of measurement difficulties, they all give different answers, two or three different methods should be used to get a range of values. One method uses the logarithmic decrement of a structure in free vibration and the damping is obtained by hitting the panel, measuring the amplitudes of two successive peaks (x_n, x_{n+1}) of the decay curve and calculating the damping factor (δ) by $\delta = \frac{x_n - x_{n+1}}{2\pi x_n}$. Other methods use the frequency response

curve of the specimen obtained with a discrete frequency noise source or a vibration shaker.

If a specimen is non-linear, some form of correction must be made since the siren test level will be considerably higher than the spectrum level of the environment. The non-linear response is most critical at accelerated test levels which may be of the order of 25 db higher than the spectrum level. Non-linearity curves are determined experimentally and plots of gage stress versus acoustic load are made right up to an estimated test level at each major resonance. As presently used by Douglas, the non-linearity correction factor is the fraction obtained by dividing the stress to load ratio that exists at the peak damage stress by the stress to load ratio that exists at the siren test load. Since the correction factor must be used in the formula to determine the siren test level, a trial and error procedure must be followed of assuming a test level, calculating a correction factor, and then checking to see that the correction factor gives the assumed test level.

If the panel responds to several modes, it is necessary to correct for this effect; if the modes are not well separated, however, or if they are coupled, the entire procedure becomes of doubtful value, and tests must then be run with a broad band source or several discrete sources so that the coupling effect is taken into account.

Two methods of applying a correction factor for multiple mode response where the modes act independent of one another has been used by Douglas.

The earlier of these methods assumes that the total rms random stress is equal to the square root of the sum of the mean square stresses of all the resonant modes excited ($\sigma_r^2 = \sigma_{r1}^2 + \sigma_{r2}^2 + \text{-----} + \sigma_{rn}^2$). The multi-mode correction is the ratio of the stress determined above to the random rms stress of the mode under consideration. The mean square stresses are determined by measuring the stresses at the peaks of the resonance curves that have been established by exciting the specimen with a siren (the sinusoidal rms stresses are used in place of the random rms stresses).

In a later method the ratio is calculated from the expression

$$B = \frac{f_{o1} \delta_1 \sigma_{s1}^2 + f_{o2} \delta_2 \sigma_{s2}^2 + \dots + f_{on} \delta_n \sigma_{sn}^2}{f_{o1} \delta_1 \sigma_{s1}^2}^{1/2}$$

which is derived by inserting the expression for the mean square stress produced by the response to random excitation of the panel in a single mode $\sigma_r^2 = \pi f_o \delta \frac{p_r}{p_s} \sigma_s^2$ into the formula for σ_r^2 . The resonant frequencies, the sinusoidal rms stresses, and the damping factors are taken from the response curve.

IV H-5 Determining the Fatigue Life

At this point we have the spectrum level of the environment at the panel location, the desired service life of the panel, and information that relates the rms sinusoidal stress in the panel to the rms random stress for given excitations. The next step is to decide how long the siren test should run and calculate the required noise level. The length of test is influenced by the following considerations.

- (a) The maximum SPL of the siren will limit the minimum duration of the test.
- (b) The higher the noise level the greater will be the effects of the non-linear response of the panel; thus the more inaccurate will be the analysis.
- (c) A reasonably large number of test cycles are necessary to insure that the test is not run in the high stress-low cycle region of the S-N curve. This would require a large extrapolation from the test to the service conditions. A test run for one hour at 200 cps would have a reasonably large number of test cycles (720,000), for example, and thus would be approaching the flatter portions of the S-N curve.

Testing times vary from company to company. Convair, Fort Worth operates a test for 3 hours, Douglas operates a test for about a half hour, while Martin, Baltimore, because of limitations on the early siren designs, ran tests for about 50 hours on P6-M panel specimens.

In general, tests should be run for between one and three hours to have an

economical test in which the sources of errors have been minimized.

It should be noted that this testing time will depend on the test SPL, which value will depend upon factors not known until the specimen has been failed so that this selected test life will only be approximate. The actual testing time will probably be within a factor of two of this chosen test time.

Once the test time is selected; then the number of test cycles at the resonant frequency of interest can be calculated. At this point the procedure becomes quite approximate and several approaches are possible.

By reference to the S-N curve for sinusoidal excitation a stress level corresponding to this test life can be selected and by dividing this stress by an assumed stress concentration factor the gage stress necessary to produce failure in the given time period is found. Using this value in the stress-load curve that has been plotted will give a required sinusoidal noise level.

The difficulty here is that values that are only known after the panel has failed must be assumed. The "stress concentration factor" is found, for example, by failing the panel and, by use of a standard S-N curve, picking the stress at which the panel must have failed. Dividing this stress by the gage stress gives the "stress concentration factor". Another approach is to use this multiplying factor to "ratio up" all the stress values on the stress-load curve, thus generating a curve of a slightly different shape and with stress values that correspond to those on the S-N curve. Once the panel has failed, all the machinery that has been set up can be put into motion. The non-linearity factor can be calculated from the corrected stress-load curve, the value of the rms sinusoidal sound pressure that corresponds to the service life of the panel can be found from the S-N curve, and the corrected stress load curve, and finally, using the equations that have been presented, the allowable random pressure (in a one cycle bandwidth) that will give the required life can be calculated.

Another approach to the testing is to assume that the panel has a linear response and to calculate a test level that will produce the same damage during the test

period as would occur during the service life. This proceeds as follows:

P_r , the rms random pressure to be experienced in service, is known. The multi-mode response factor B is calculated; since the panel is assumed linear, the non-linearity factor A is unity, and the siren level to produce the same rms stress, P_s , can be calculated. The sinusoidal S-N curve is now entered at the number of cycles expected in service and at the number of cycles expected for the siren test. Since the panel is assumed linear, the ratio of the test stress to the service stress is the same as the ratio of the test pressure to the service pressure and 20 times the \log_{10} of this ratio is the db pressure difference. This db difference added to P_s gives the required test level. Since the panels are usually non-linear, this level will be lower than it should be. Again, once the panel has failed, all the proper corrections can be made and the expected panel life or the permissible noise level calculated.

If it is felt that the test load calculated may lead to abnormally long testing times, a step method can be used. Beginning with the test level calculated on the basis of a linear panel response, the test pressure on the panel is increased in 3 db increments every 20 or 30 minutes until the panel fails. After failure, the number of cycles corresponding to each load is known and also the strain gage reading at each load. A process of trial and error, using a standard S-N curve, must be used to determine an equivalent sinusoidal test level at which the specimen would have failed. For example, if only two test loads were involved, Miner's damage rule would be

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} = 1$$

where n_1 and n_2 are the known test cycles. The gage stress ratio $\frac{\sigma_1}{\sigma_2}$ is known from the test and is equal to the ratio of the stresses that correspond to N_1 and N_2 from the S-N curve (call them $\frac{S_1}{S_2}$). N_1 is assumed and the stress S_1 taken from the curve; S_2 is now known and N_2 can be taken from the curve. N_1 and N_2 are put in the equation to see how they check, and the process is repeated until the equation is satisfied. Once the

equation is satisfied, the relation between measured gage stresses and S-N curve stresses is known and the analysis can proceed as before.

When a panel has two or three major resonances that produce similar stress levels, then tests must be performed for each resonance. The resonance that gives the shortest predicted life determines the design life of the panel.

The methods described can be codified in many ways so that they can be performed quickly. If two or three panels of a given design are failed, much of what appears like guess work in the explanation, can be estimated with reasonable success and adequate designs developed.

It should be emphasized that considerable design work is done during proof testing. The specimens, whether they be a complete vehicle or a small section, are well instrumented so that if a failure occurs, information is available that is useful for making re-designs. Also design changes are often made during the proof tests and life predictions made from strain gage data. These procedures are not as involved as the siren tests and the Section III A-5 on Boeing, Seattle has a discussion of how jet engines have been used to make design changes.

IV H-6 Bibliography of Publications useful for predicting sonic loads

1. McClymonds, J. C., Sonic Fatigue Design Analysis, Proceedings Fatigue of Aircraft Structures, Wright Air Development Center, WADC TR59-507, August 1959.
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IV 1 RECOMMENDED PROCEDURES FOR PROOF TESTING

IV 1-1 Proof Testing of Aircraft Structures

The only noise source that is currently used for proof testing aircraft structures is the jet engine. It is used on the test stand to prove small structural segments or specimens and on the completed vehicle during full scale run-up tests.

All of these tests are accelerated in one way or another. When a vehicle operates with afterburners most of the damage is assumed to occur at this time so that a jet engine test run for the full afterburner life of a plane (10 or 15 hours) is considered adequate. In those instances where afterburners are not used in operation, the duration of service exposure to maximum sound pressure levels tends to be of the order of one or two hundred hours and to shorten the testing time tests are run at higher levels than ever would be experienced in service. These higher levels can be obtained by operating the vehicle with afterburners (assuming that no large changes in directionality patterns occur) or by operating it at low ambient temperatures to get increased engine thrust (a plane was tested in Alaska by Douglas). If a test time is selected, then an approximate test SPL can be calculated by assuming a linear panel response, assuming an average resonant frequency (say 200 cps), and then using an S-N curve to determine the stresses that would exist at the test life and the service life. As was explained in Section IV H-5 this can be converted to an SPL difference that can be added to the service SPL to give the required test pressure. In this instance the test pressure is lower than would be obtained if the maximum stresses and the non-linear characteristics of the panels were known and used with the fatigue curves, and actual service lives are predicted from the test failures that occur.

A slightly different procedure has been used by Boeing, Seattle. It involved determining the duration and level of the various sonic loads from the mission profile of the vehicle, and by means of Miner's rule, by assuming a Rayleigh peak stress distribution, (or by measuring the distribution), and by simple panel tests, developing a curve to relate the life of a panel in the test environment to its service life. This has many of the features

of design testing and requires that testing be continued until the panels fail in order to predict the service life.

For single full scale proof testing, the first method described appears to be successful and those structures that have withstood a 10 or 15 hour test with full thrust or with afterburners have not become maintenance problems. This is a severe test and it would be very surprising if such were not the case.

Proof tests have also been performed with jet engines operating in a test cell. This environment is quite different from the free-field environment around the vehicle and in many cases, because of the reverberant sound build-up, is a more severe environment. In general, the methods of relating test time to test SPL are the same with in-cell testing as they are with full scale tests.

Before proceeding with our recommendations it is desirable to give a very brief history of the sonic fatigue testing of a few planes to show the emphasis that has been placed on proof tests and how in many instances there is no clear division between design and proof testing.

Sonic Testing of the B-52

During initial run-up tests of the B-52, wing trailing edge and flap failures occurred that were attributed to sonic fatigue, and to deal with this problem, Boeing set up a siren test facility in 1952. Comparison tests were made on panels in the siren facility and a full scale airplane was run at maximum wet thrust for 5 hours. As a result of these tests the trailing edge of the B-52 wing was re-designed and tested in an engine test cell with two jet engines operating at maximum military wet power. While many of these re-designs were satisfactory, when new engines (the J57-P-43W engines) were specified, the service noise levels increased and new SF problems arose. An airplane using the new engines was subjected to the equivalent of 219 minutes of wet thrust operation on the ground, and measurements showed there was a sound level increase of 4 to 5 decibels which resulted in more failures that had to be corrected. Many of the re-designs that were made as a result of earlier proof tests with the smaller engines proved to be satisfactory with the new

higher powered engines.

The production of the B-52 was then taken over by the Boeing, Wichita plant, and the first proof test arrangement at Wichita consisted of two J57-P-43W engines mounted on a stand simulating the actual airplane configuration. A comparison of noise levels and the structural failures that occurred in this test and earlier full scale tests indicated that the installation was representative of the actual airplane and environment. Although many of the previous fixes gave little trouble, failures occurred in other areas and maintenance problems continued. The latest test set-up at Wichita is a complete production 4-engine B-52 half wing mounted on two supports. From October 1958 through October 1959, this B-52 half-wing was subjected to 10 hours of wet take-off thrust. With the exception of two periods of 5 minutes each at the beginning and end of the test, all testing was with production lobe-type sound suppressors installed. During the first 4 hours of test time, 230 minor failures occurred which required 740 man-hours to repair. Most of these failures were considered to be of a normal maintenance type and did not require re-design.

Sonic Testing of the Boeing KC-135

The first acoustic fatigue tests were made with a siren and the panels were placed normal to the incident sound. These tests provided reasonable estimates of the relative fatigue and endurance capability of various designs, but it was concluded that tests should be made on the airplane before and after a design change was made to assess properly the effect of the change on the fatigue life. Stress and SPL data on the KC-135 was obtained from microphones and strain gages attached to the exterior of the fuselage and from proximity pick-ups which were hand held to the interior of the structure. A design analysis was performed on this aircraft using measured stress data (see Section III A-5) and the service life of the re-designed parts was predicted.

Sonic Testing of the Douglas RB-66 Aircraft

In February of 1958 an accelerated proof test was conducted on a complete RB-66 aircraft in Alaska. The test was conducted in Alaska because the low ambient

temperatures caused the engines to produce noise levels 3 or 4 db higher than in the normal service environment. At these high sound levels a 10 hour test was estimated to be approximately equivalent to 10 years of normal service life (150 hours of maximum thrust operation at a rate of 15 hours per year). In ways that we have outlined, curves were prepared that could be used to estimate the life of a part that has failed in accelerated tests at high sound pressure levels. They could not be used to predict the life of a structure that had not failed during the test, although it could be assumed that those panels that withstood the test would have a satisfactory life.

A series of 10 hour in-cell proof tests were conducted from June to November of 1958 at the Long Beach facility. These tests were to see if the aileron-elevator and rudder re-designs made as a result of the Alaska tests would be adequate for the life of the aircraft. The tests were made in a jet engine test cell with an Allison J71-A-13 engine, and to check the test environment panels were instrumented on the plane and the vibration response of the structure and the SPL were measured while the engines were operated at maximum power. Again the tests were conducted at sufficiently high sound levels so that a 10 hour proof test was equivalent to the life of the aircraft at normal sound levels. There was considerable difficulty comparing the aircraft and test cell sound environments since the frequency distribution in the test cell was different from that on the aircraft, but SF life predictions were still made on panels that failed.

Sonic Testing of the Douglas DC-8

On this plane, extensive siren design tests were made prior to the proof tests and the proof tests themselves were made on a jet engine stand. Accelerated tests with the engines operating at full afterburner thrust were performed (the plane does not use an afterburner in service). Details of this testing were not available but it is our understanding that full scale proof tests were not performed on any prototype vehicles.

Sonic Testing of the Convair B-58

Semi-qualification proof tests were carried out in a semi-enclosed jet engine stand and a final proof test was performed on a complete vehicle. Both tests involved

operating the engines for 10 hours with afterburners.

IV 1-2 Recommended Procedures

In the past a great deal of re-designing was done during the proof testing. If the design methods recommended in this report are followed, much of this re-designing can be eliminated and if the sequence is followed, (1) design testing, (2) semi-qualification testing with broad band sources, and (3) full scale proof testing, the final proof test should bring about little re-design.

There are several reasons for the final full scale test:

- (1) Characteristics of the operating environment are closely duplicated.
- (2) The problem of simulating boundary conditions on specimens is eliminated.
- (3) Any interaction between adjacent panels will be taken into account.
- (4) Since only those panels that are expected to give trouble are tested, there will always be a few unexpected trouble spots that must be found (certainly not every panel on the plane can be siren tested).
- (5) The final test is necessary for other items that may not have been checked in preliminary tests such as hydraulic lines, electrical lines, and electronic or mechanical equipment.

Semi-qualification tests using broad band sources such as Aero-Medical Laboratory sirens or the air modulated speaker (and banks of BBN sirens if available) are recommended because we feel that the designs made with the discrete frequency siren (because of boundary simulation, multi-mode response, and correlation problems) require additional verification before incorporation in the aircraft. These broad band tests should be conducted on fairly large sections of structure (larger than is used in siren tests) to duplicate boundary conditions and panel interaction effects.

The final proof test should be well instrumented and the test time should be based on the total duration of afterburner operation in service or calculated from the mission profile as has been described. During the test, strain gage and SPL data should be collected and compared with the values used in the various preliminary tests. If possible, strain gages

should be located at the precise location they occupied during the siren tests so that direct stress comparisons can be made.

IV 1-3 Proof Tests for Missile Structures

Although proof tests have been performed on missile structures by Boeing in connection with the Minute Man and Dyna Soar program, the noise levels involved were quite low and were not considered damaging to missile structures. The Titan missile, however, required a proof test of substantial levels to be imposed on structural segments for short periods of time. The details of the method used by Martin, Denver are given in Section III-1 and involved exciting the structure with a broad band siren over a 9 square foot area at a sound pressure level of 166 db for a period of 10 minutes.

It is expected that it will be difficult to obtain random acoustic excitation of a level equivalent to the sound pressure levels expected from large missiles (175 to 185 db). By use of the design theory now used in sonic fatigue analysis, however, it would be possible to perform decelerated tests. Service exposure time for a missile is usually quite short so that a test could be run for several hours at a low SPL that would produce the same damage as the short service exposure to a high SPL. Broad band sources such as modulated air flow speakers, broad band sirens and, if extensive tests are not necessary, jet engines should be considered for such use. When a single mode predominates, discrete frequency tests could be run (the WADD facility can produce 174 db at discrete frequencies). Certainly such tests are to be preferred to any full scale missile tie-down tests. It is vitally important that proof tests be performed on missile structures that are exposed to high intensity noise since a sonic fatigue failure could result in a total loss of the rocket.

IV J SOME RECOMMENDATIONS FOR FUTURE WORK

There are many research programs being performed throughout the world that aim at an improved understanding of the many factors that must be considered when dealing with sonic fatigue. Obviously programs concerned with defining acoustic environments around vehicles; with investigating scaling laws for model jets; with developing cumulative fatigue damage theories; or with considering ways of using energy techniques for determining fatigue life are of considerable benefit and will contribute toward the development of comparatively inexpensive and reliable sonic fatigue design techniques.

Since the necessity for this type of work is well understood, our recommendations are more specifically directed toward immediate (the next three or four years) ways of reducing the cost of sonic fatigue design and improving the accuracy of the methods and also toward the delineation of specific problems that must be considered.

1. Broad band noise sources have been recommended for semi-qualification tests and work should be done on the correlation properties of broad band sirens, air modulated speakers, arrays of discrete frequency sirens, and Norair generators, to compare them with jet engines and rockets. Precise ways of utilizing these sources in testing should be developed for they offer a considerable saving in the proof testing of structures.
2. Experimental and analytical studies on the combined environments, temperature, pressure, and corrosion are necessary.

The feasibility of using present design methods with heated specimens should be determined, and experimental investigations on small scale heated specimens should be made to see whether heating during a full scale proof test is necessary or whether the results can be predicted from semi-qualification proof tests on smaller sections.

The corrosive effects of vehicle operating environments must be investigated and tests must be performed on panels to assess the effects of conjoint corrosion and

fatigue on their sonic fatigue life. Ways of simulating corrosion during combined tests must be studied.

3. An experimental and analytical investigation of the design methods used by the various facilities should be made by testing identical panels in each facility and comparing the results. This would allow a comparison of the prediction techniques and an assessment of the effects of multi-mode response and mounting conditions on the results. If methods for determining fixes for failure are ever to be in any way standardized without using full scale proof tests, such an experimental comparison of facilities is necessary.
4. Methods of performing design and proof tests on missile structures require considerable study. Experiments to check the results of decelerated testing should be made since such a test procedure could save large sums of money by permitting the use of relatively low sound pressure levels during testing.
5. An analytical and experimental investigation should be made of the usefulness of orienting a specimen at an angle to a plane progressive wave in a discrete frequency siren chamber as a means of simulating correlation functions.

The incorporation of correlation effects will require the compilation of the correlation properties of representative noise fields and efforts should be made to deduce simple approximate representations of these properties in terms of plane wave conditions for use in design.

6. Some general investigations that should be performed are:
 - (a) Experimental investigation of the types of modes excited on actual structures.
 - (b) Experimental and analytical investigation to determine the response of stiffened cylinders (shell structures with uniform stiffener spacings or walls made from honeycomb material) such as are encountered in missiles. The response to discrete frequency and random excitation should be determined.
 - (c) Experimental and analytical studies of non-linear and multi-mode correction factors for use in design.

- (d) A theoretical study of the use of energy techniques in predicting fatigue life.**
- (e) Experimental and analytical evaluation of the effects of various boundary conditions on the response of panels.**
- (f) Studies of possible ways of simulating flight loads on a specimen undergoing a sonic fatigue test.**

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Rpt No. ASD-TR-61-185. SURVEY AND EVALUATION
OF SONIC FATIGUE TESTING FACILITIES. Mar. 62.
377 p. incl illus., tables. 19 Refs.

Unclassified Report

Sonic fatigue testing facilities were surveyed and evaluated to establish present methods and techniques of testing and to determine necessity of performing other environmental tests with high intensity noise. Fifteen facilities were visited, and detailed descriptions of these facilities are presented. Facilities were considered as to design, proof testing, research tools, sound sources, the theoretical background of sonic fatigue work, test methods and specimen arrangements, instrumentation and data acquisition, time and costs, and combined environments. Also most feasible design

(over)

and proof testing procedures considered within present theory and equipment framework are presented.

Most economical procedure for developing sonic fatigue resistant structures consists of (1) design panels with discrete frequency siren methods, (2) perform semi-qualification tests with broad-band sources such as broad-band sirens or modulated air flow speakers--not jet engines, and (3) perform full-scale proof test. Effects of temperature and pressure can only be assessed by combined tests. In many instances, effects of correlation can be approximated in a discrete frequency siren test by orienting a specimen in manner determined by consideration of sound-level contours existing on the aircraft. Combined tests for nuclear radiation should not be considered.

1. Test facilities

2. Sonic fatigue

I. AFSC Project 1370,

Task 13963

II. Contract AF 33(616)-70C3

III. COMESCO, Consultants

In Engineering Science,

Arlington, Massachusetts

IV. R. A. Bianchi, R. T.

Bradshaw, J. H. Farrell,

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1. Test facilities

2. Sonic fatigue

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IV. R. A. Bianchi, R. T.

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